NOVACAST

Scottish Branch ICME

Oct 2019

Don Tittensor
Technical Sales Manager

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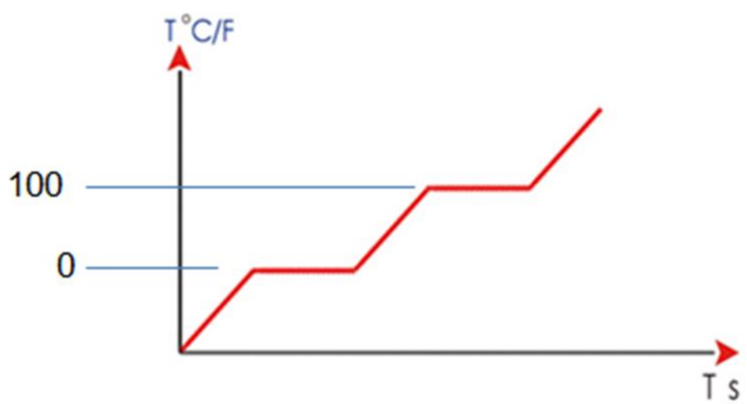
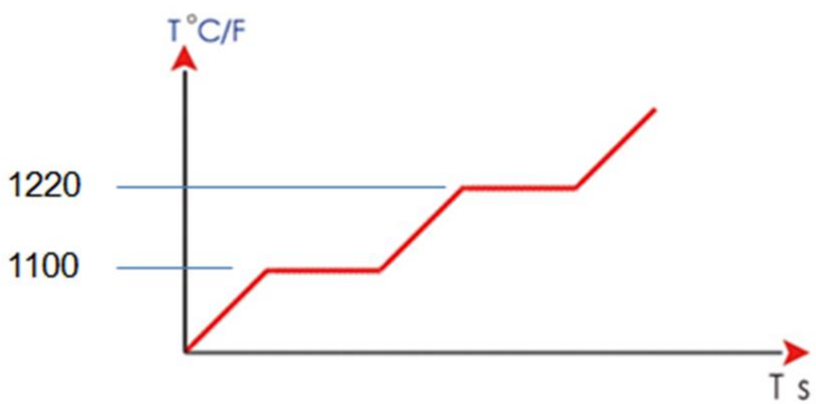
Asmet
Source of Strength

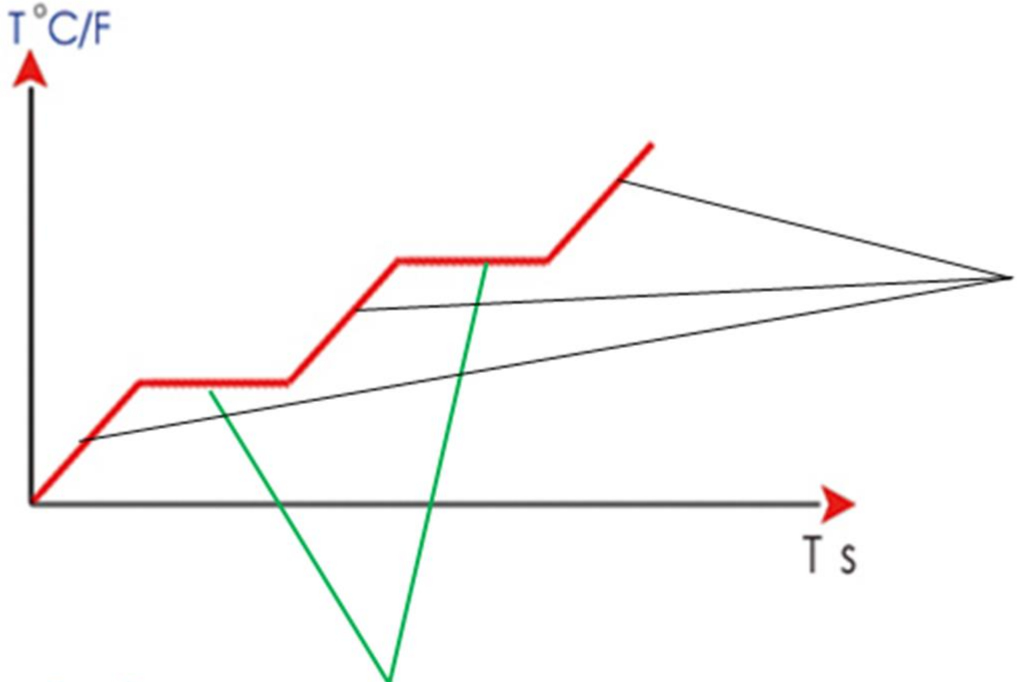
Controlling Melt Chemistry Using Thermal Analysis

Thermal Analysis Basics



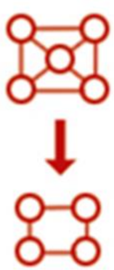


Specific Heat and Latent Heat



Specific Heat.

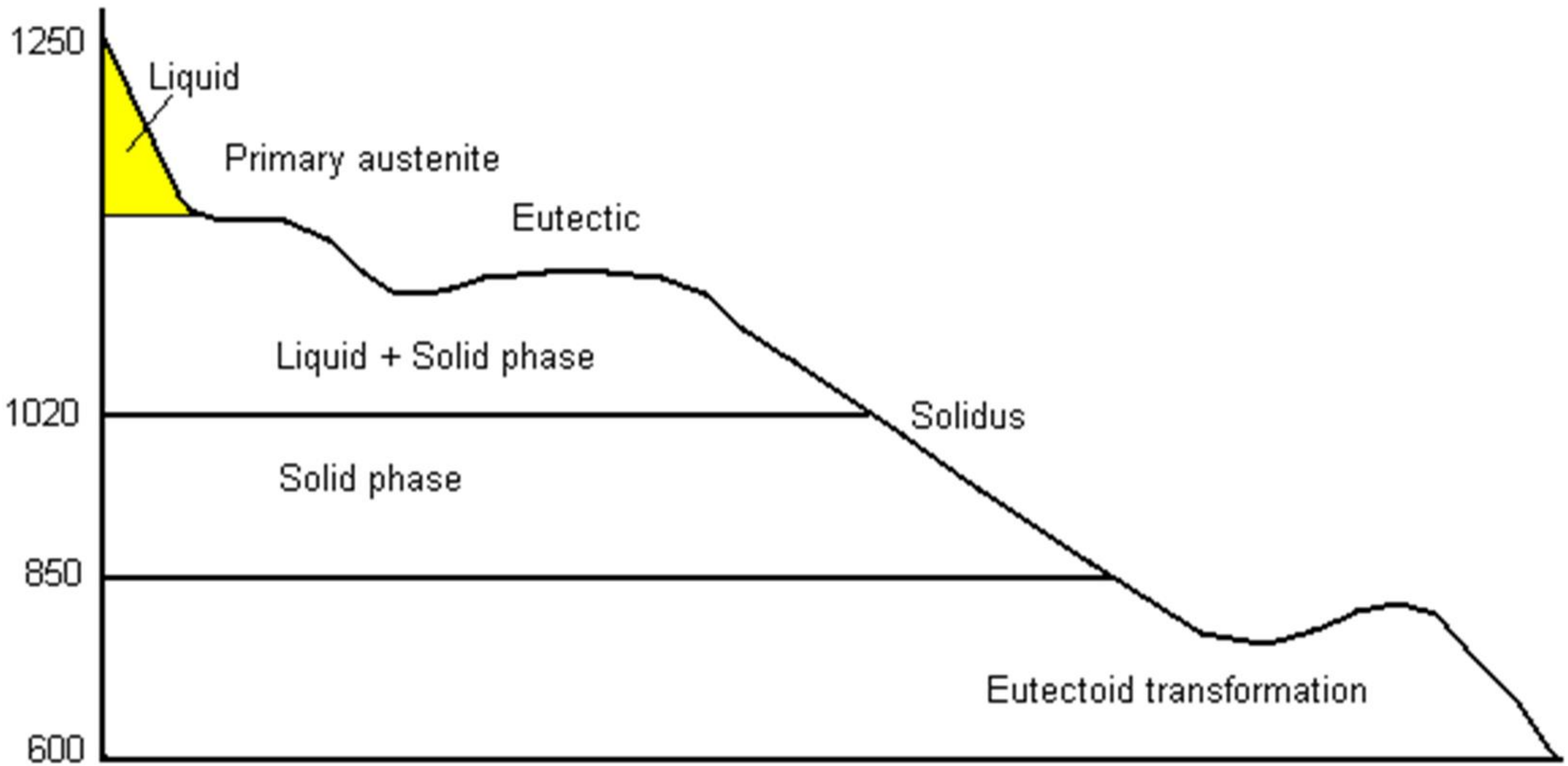
The energy required to move atoms



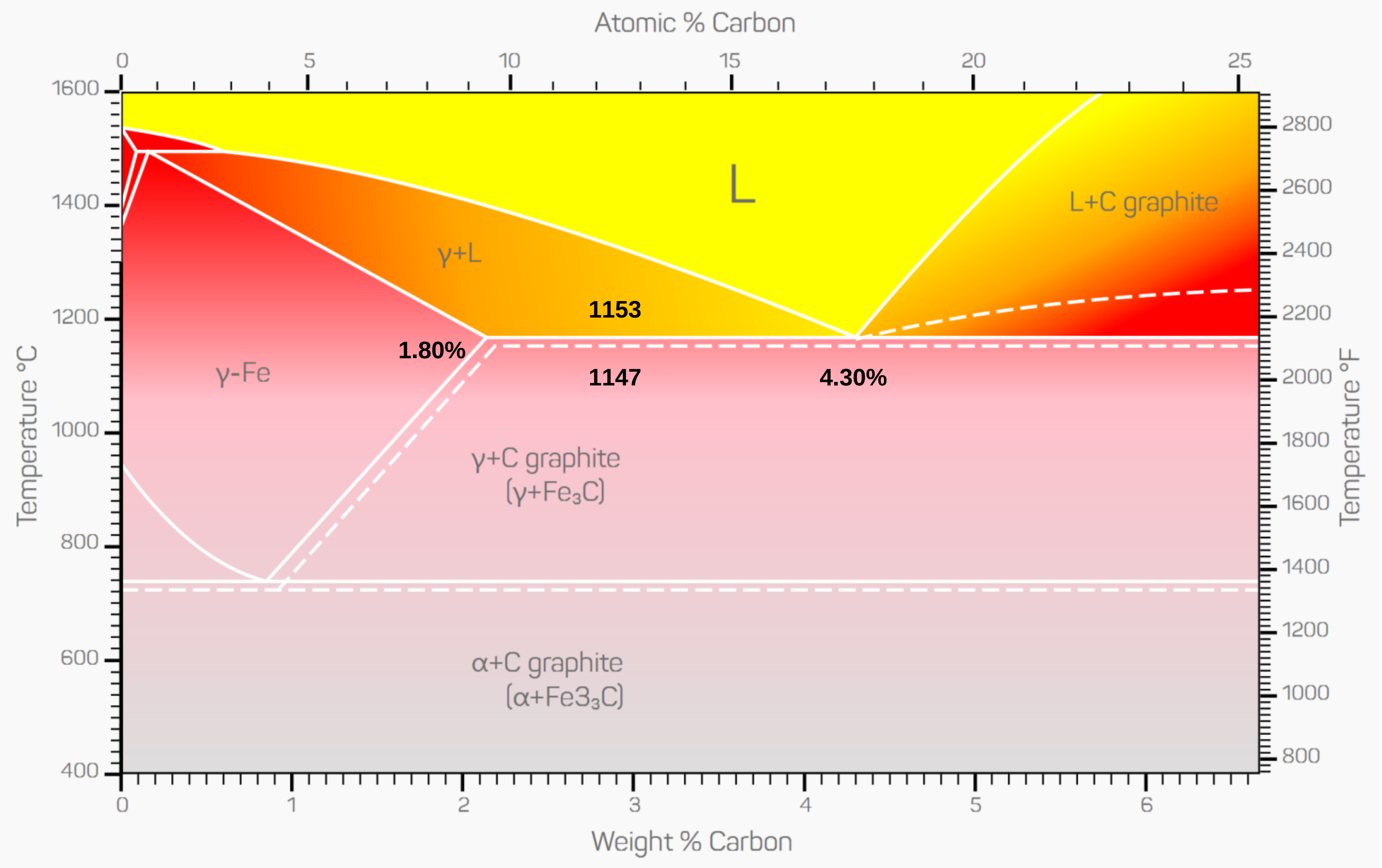
Latent Heat.

The energy required to change structure

Arrests on Cooling

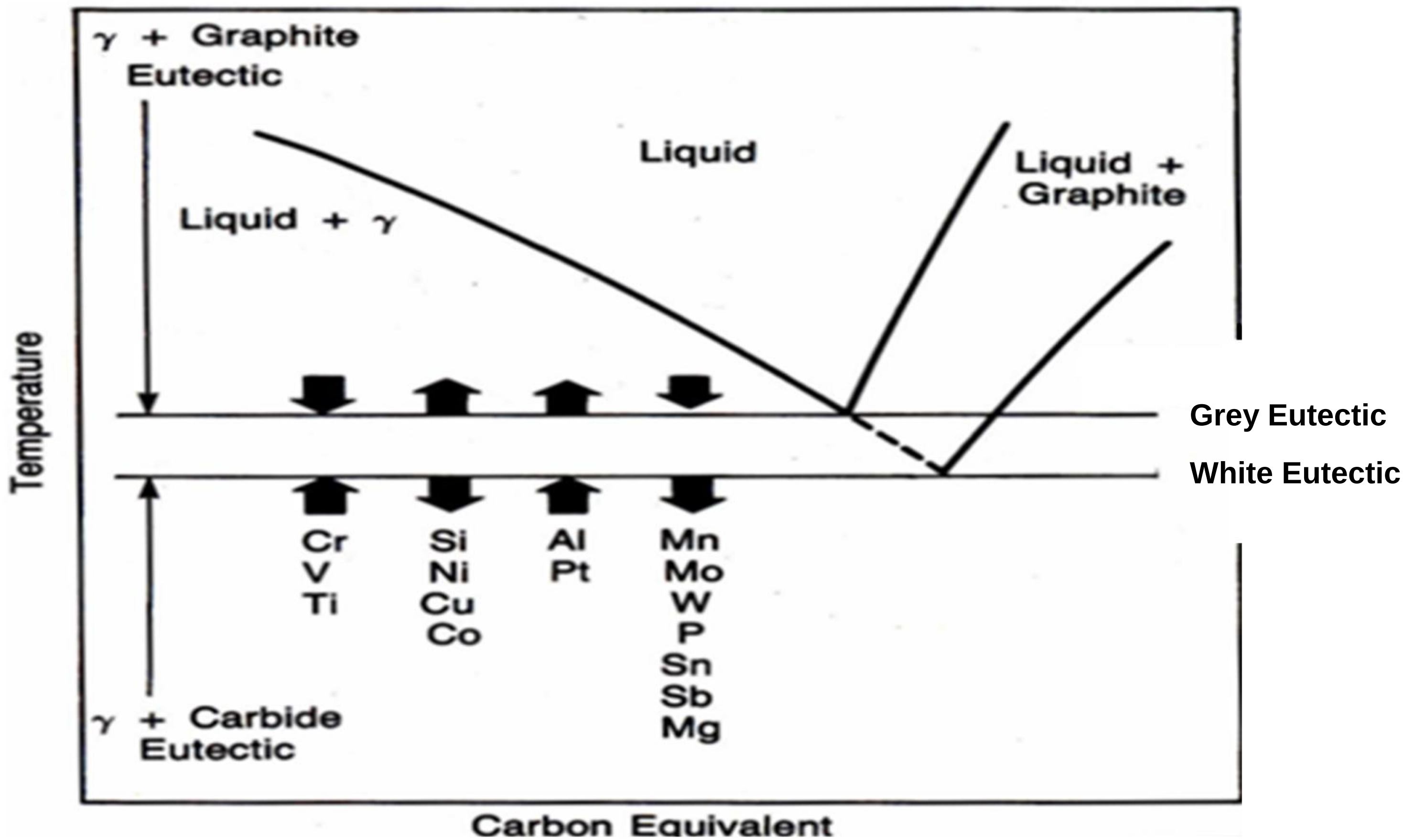


Fe-C Equilibrium Diagram



Note the temperature difference between the Grey and White Eutectics for a simple Fe-C system

Effect of Elements



When alloying and trace elements are included, the temperatures of the Grey and White Eutectics diverge.

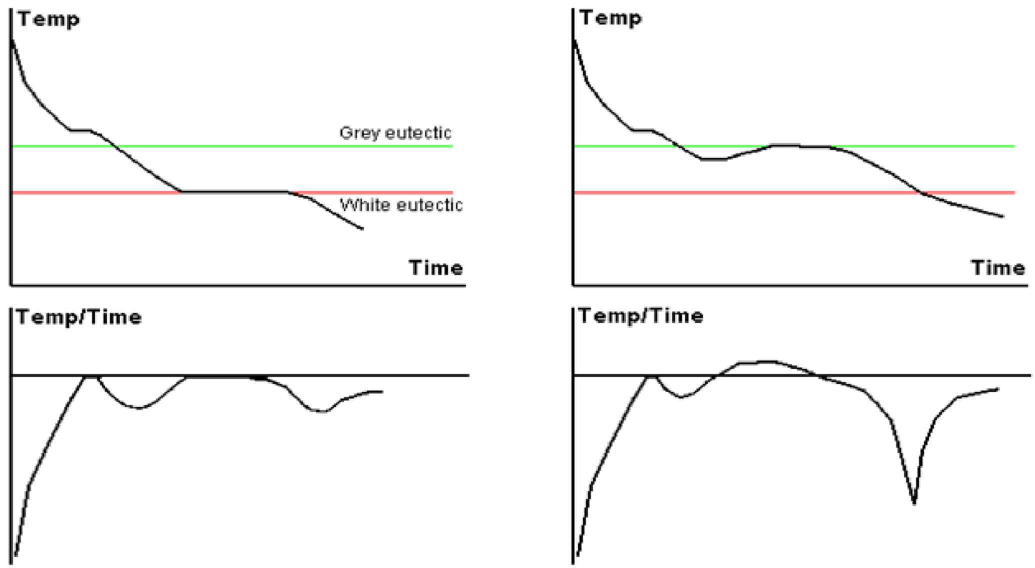
We now have to refer to a ‘Iron – CE’ Phase Diagram.

Effect of Elements

- When issuing a required analysis to the foundry, the three reference temperatures, TL, GE and WE are already set, based on the issued chemistry.
- The foundry must find and establish these temperatures (within limits) using thermal analysis in conjunction with spectrographic analysis.
- TL is fixed by the chemical carbon equivalent and is mainly influenced by the Carbon, Silicon and Phos. content.
- GE and WE are influenced by many of the elements, **except** carbon.
- Once the values have been established (for each grade), the aim should be to maintain them, within limits, for all future melts.

TL	+/- 5C or better
GE	+/- 2C or better.
WE	+/- 2C or better.

White and Grey Solidification



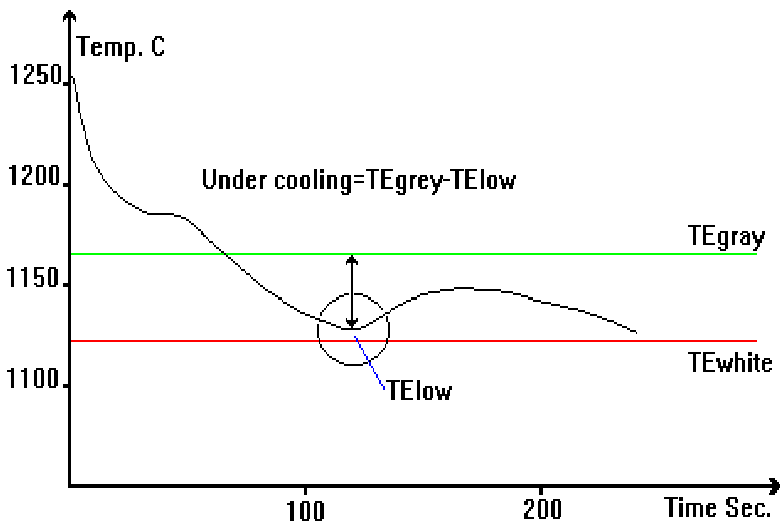
Both White (Te) and Grey (Plain) cups will measure TL.

Te cups (S-Te cups for treated SG) will measure the white eutectic (WE).
WE can also be classified as the <u>Silicon Equivalent</u>.

The Grey Eutectic (GE) is measured using a Grey cup.
To ensure GE is achieved the sample must be <u>fully inoculated</u>.
GE will be TEHigh from a fully inoculated sample.

Under Inoculated ?

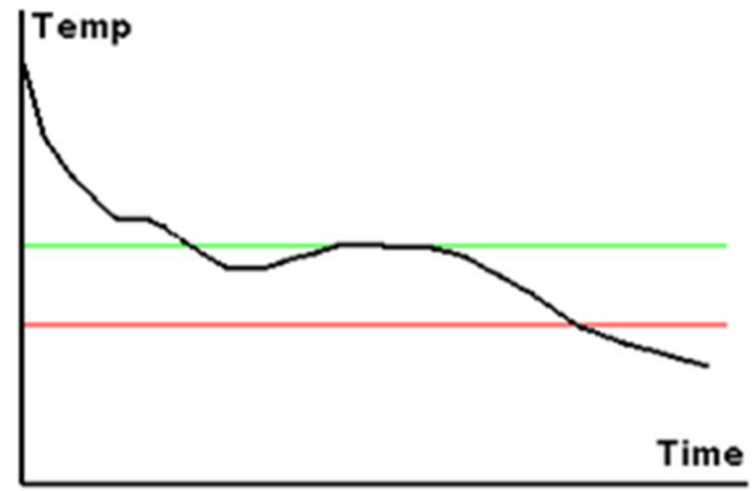
Ladle Sample



TELow is very low.
TEHigh does not reach the Grey Eutectic.
Recalescance may be low.

Inoculation has <u>not</u> been optimised.

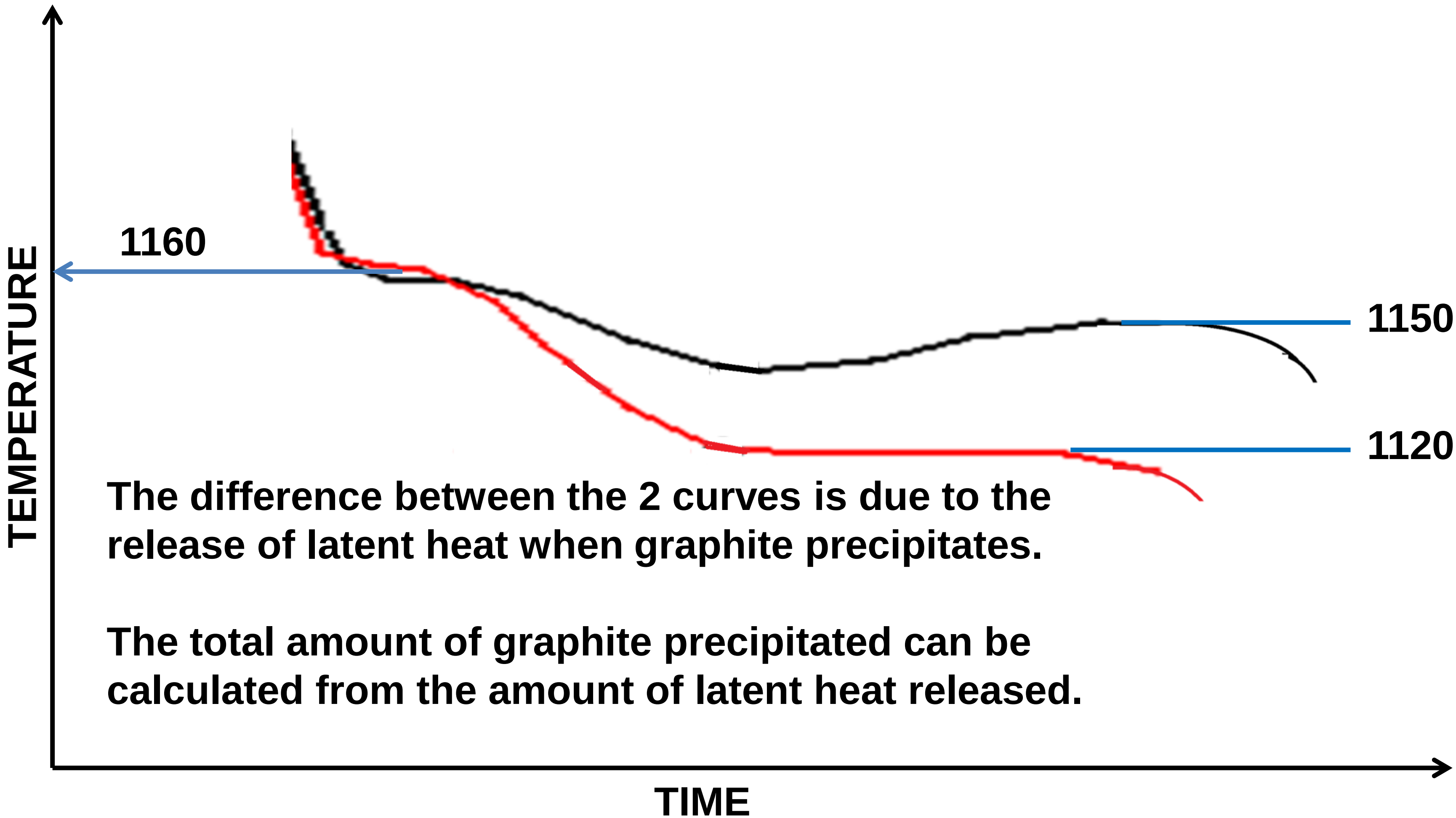
Extra Inoculant in the sample cup



TELow is high.
TEHigh reaches the Grey Eutectic.
Recalescance is low.

Inoculation <u>has</u> been optimised.

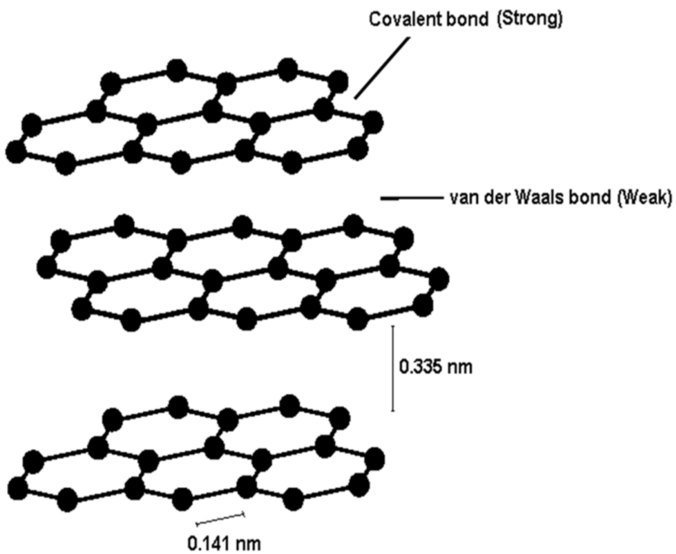
White and Grey Solidification



The difference between the 2 curves is due to the release of latent heat when graphite precipitates.

The total amount of graphite precipitated can be calculated from the amount of latent heat released.

Carbon-the essential element

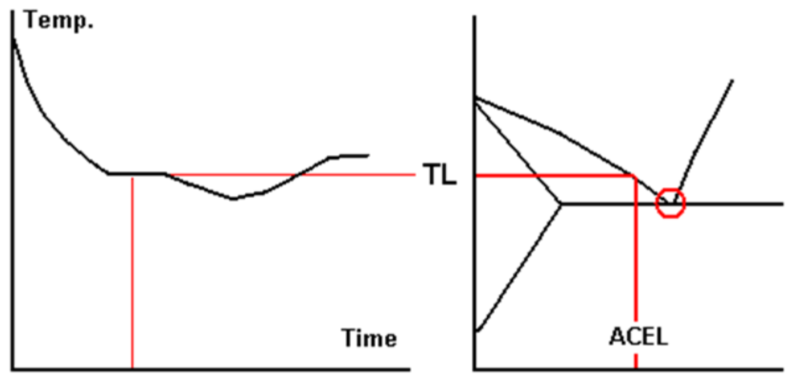


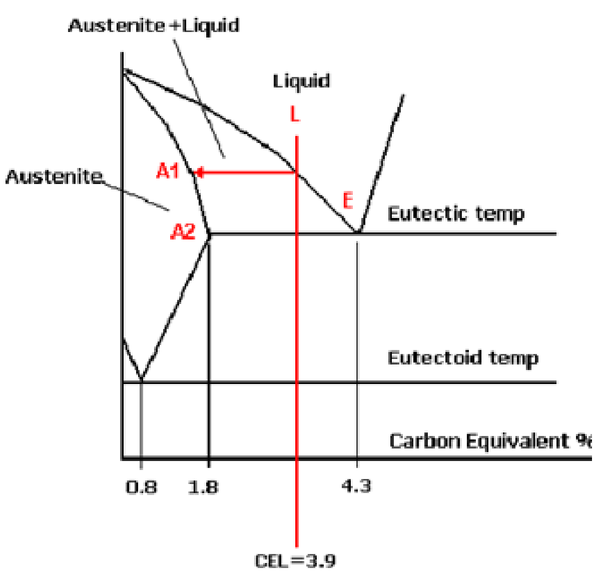
Non Metallic	
Atomic weight	=12.01
Atomic number	= 6
Density as graphite	= 2.23 **gm/cm3**
Density as diamond	= 3.52
Melting point	= 3527 C
Latent Heat	**= 3600J/gm**

Total Carbon =
Carbon dissolved in Austenite + Carbon combined as Carbides
+ Carbon precipitated as Graphite.

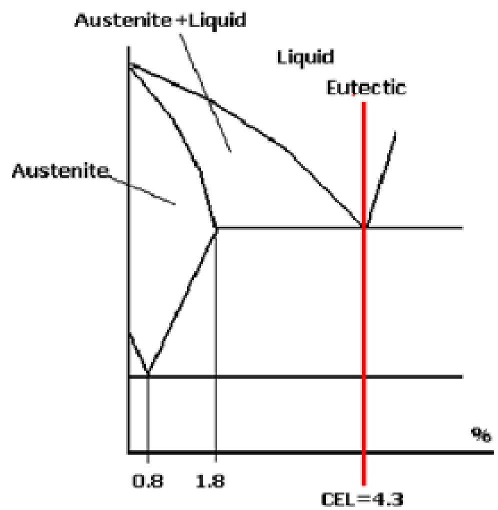
Active Carbon =
Carbon Precipitated as Graphite, measured by ATAS based on cooling curve data.

Carbon Equivalent Liquidus (CEL)

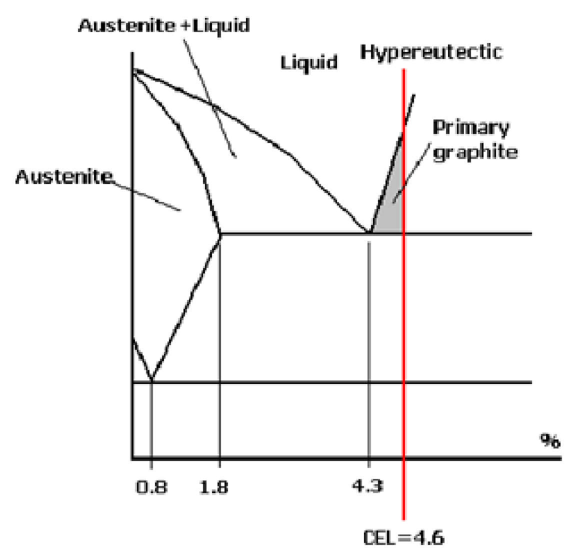




Hypo

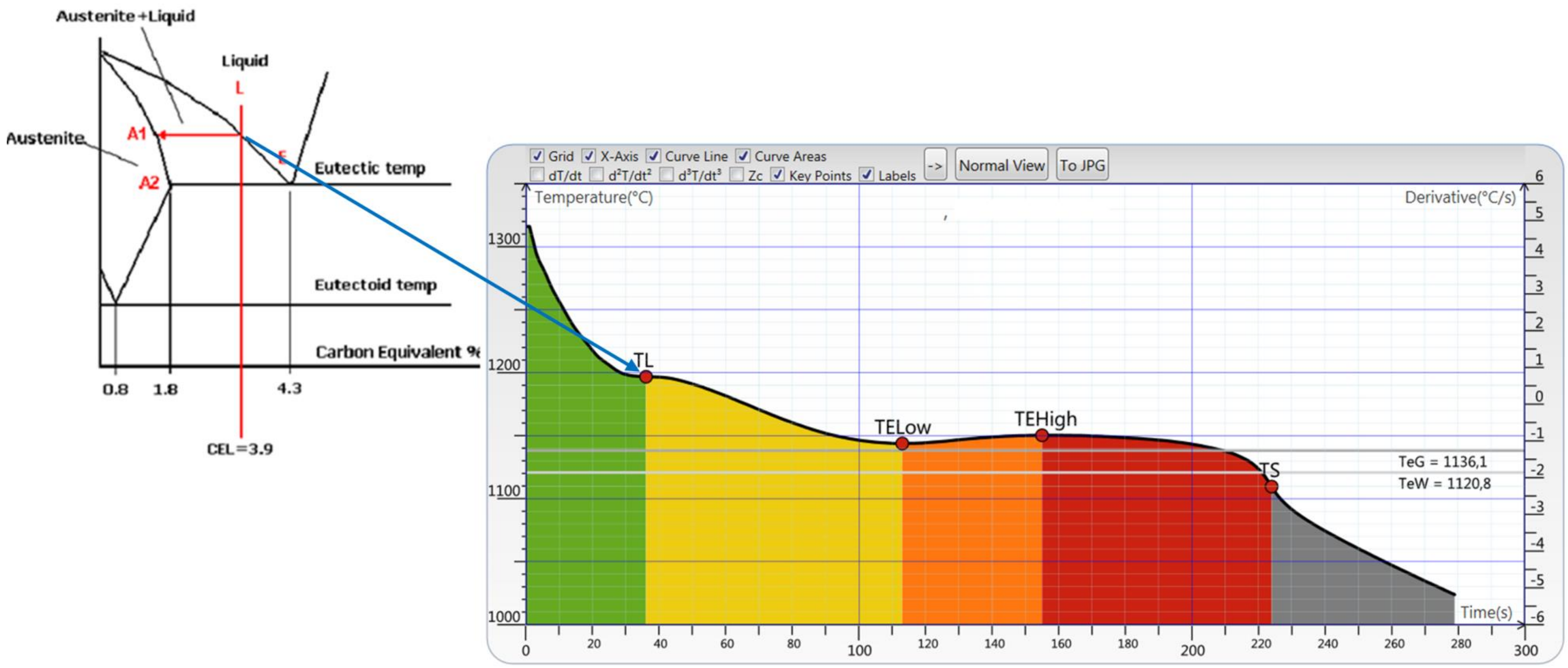


Eutectic

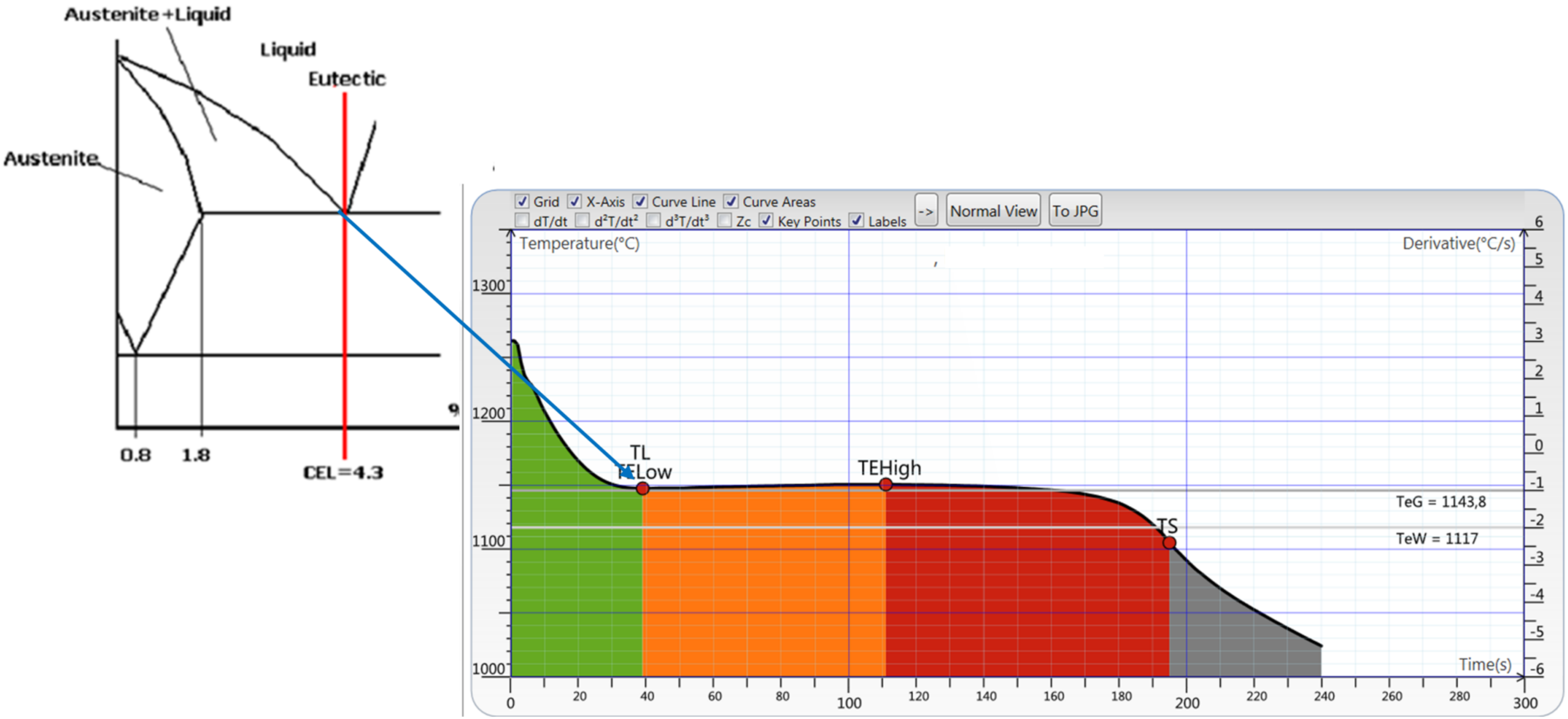


Hyper

Hypo Eutectic

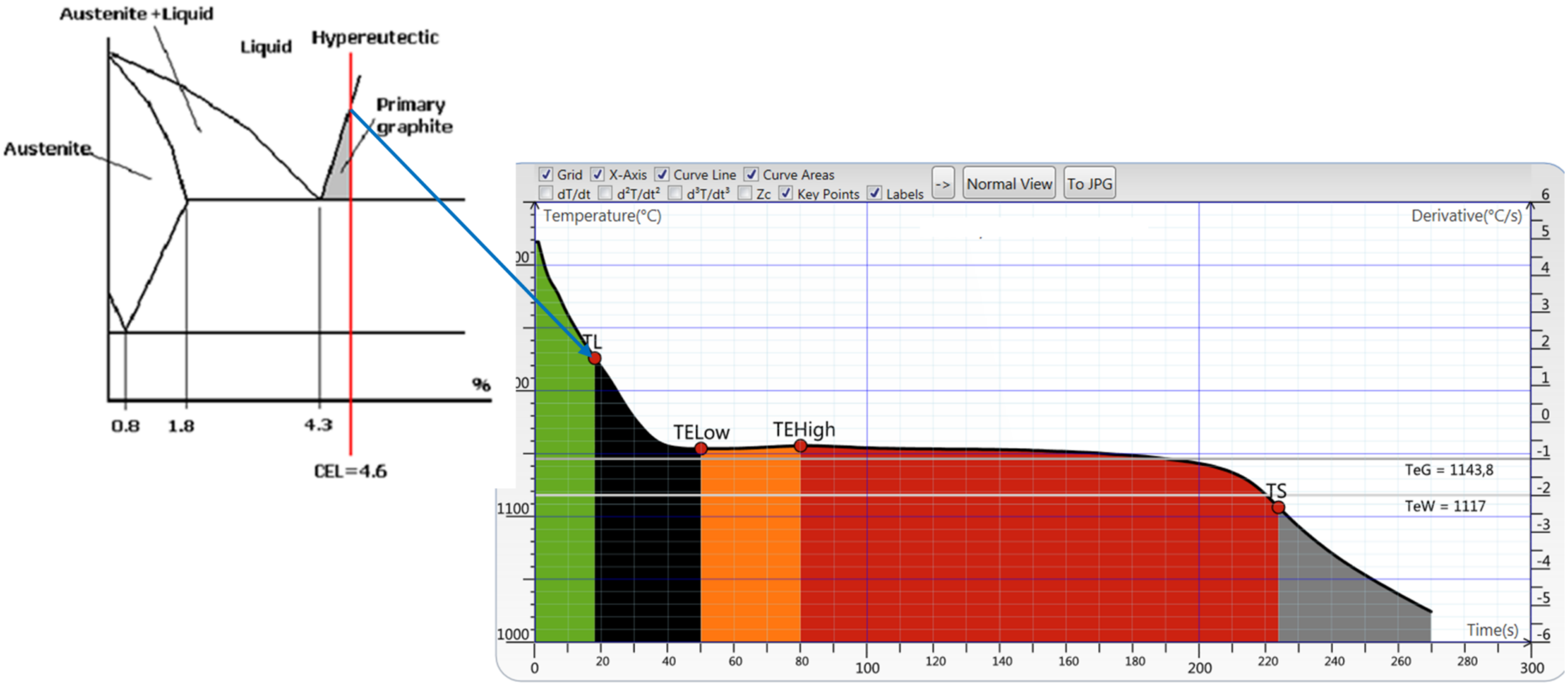


Eutectic

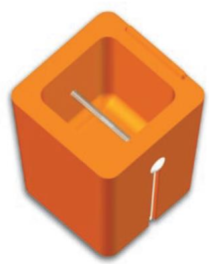


Austenite+Liquid
Liquid
Eutectic
Austenite
0.8
1.8
CEL=4.3
Grid
X-Axis
Curve Line
Curve Areas
dT/dt
d²T/dt²
d³T/dt³
Zc
Key Points
Labels
->
Normal View
To JPG
Temperature(°C)
Derivative(°C/s)
1300
1200
1100
1000
TL
TELow
TEHigh
TS
TeG = 1143,8
TeW = 1117
Time(s)
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6

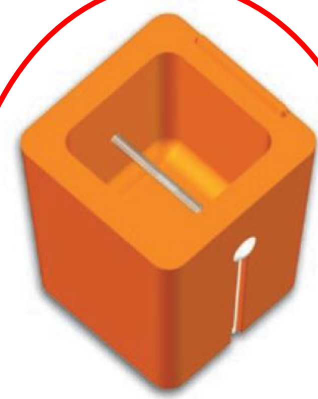
Hyper Eutectic



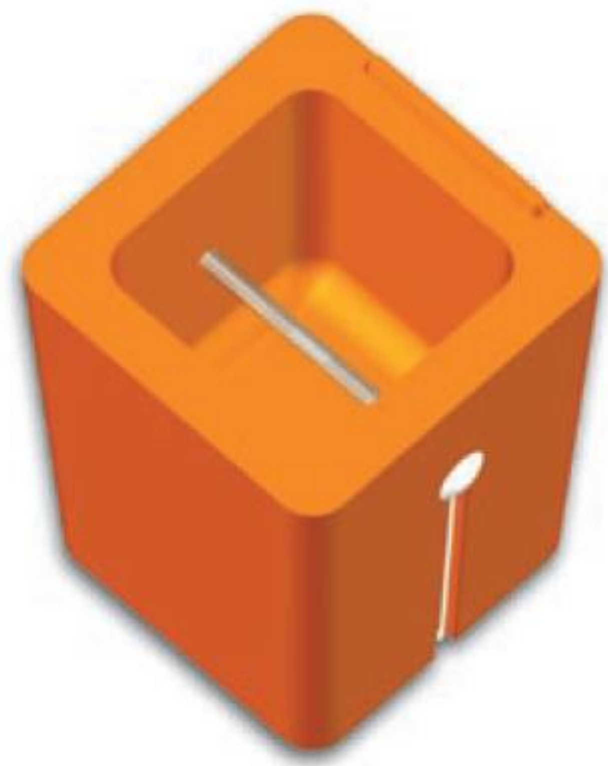
Chemistry vs Modulus



M = 0.4 cm



M = 0.75 cm



Modulus = Volume/Cooling Surface Area

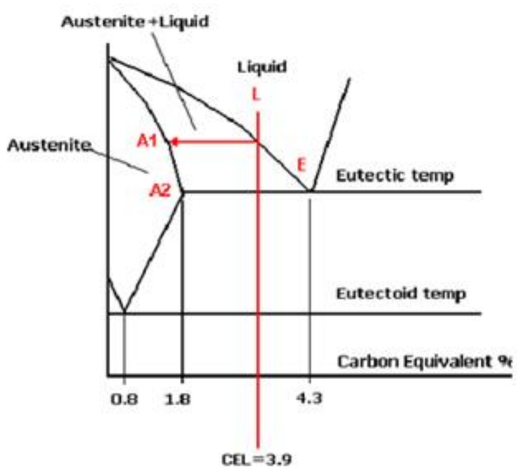
M = 4.0 cm

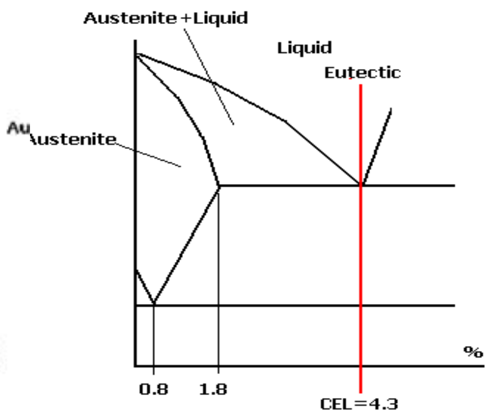
Chemistry vs Modulus

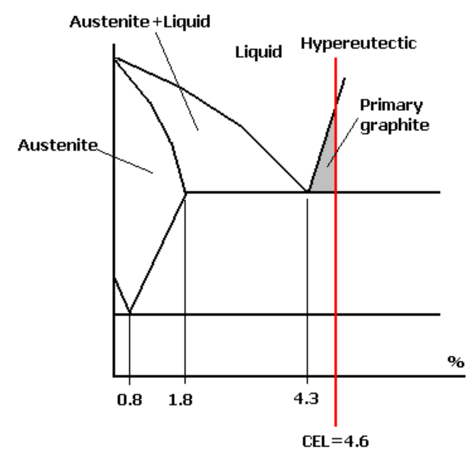
M = 0.40 cm

M = 0.75 cm

M = 4.0 cm







Metal of the same analysis will give different results within the casting depending on casting modulus.

Chemistry vs Significant Modulus

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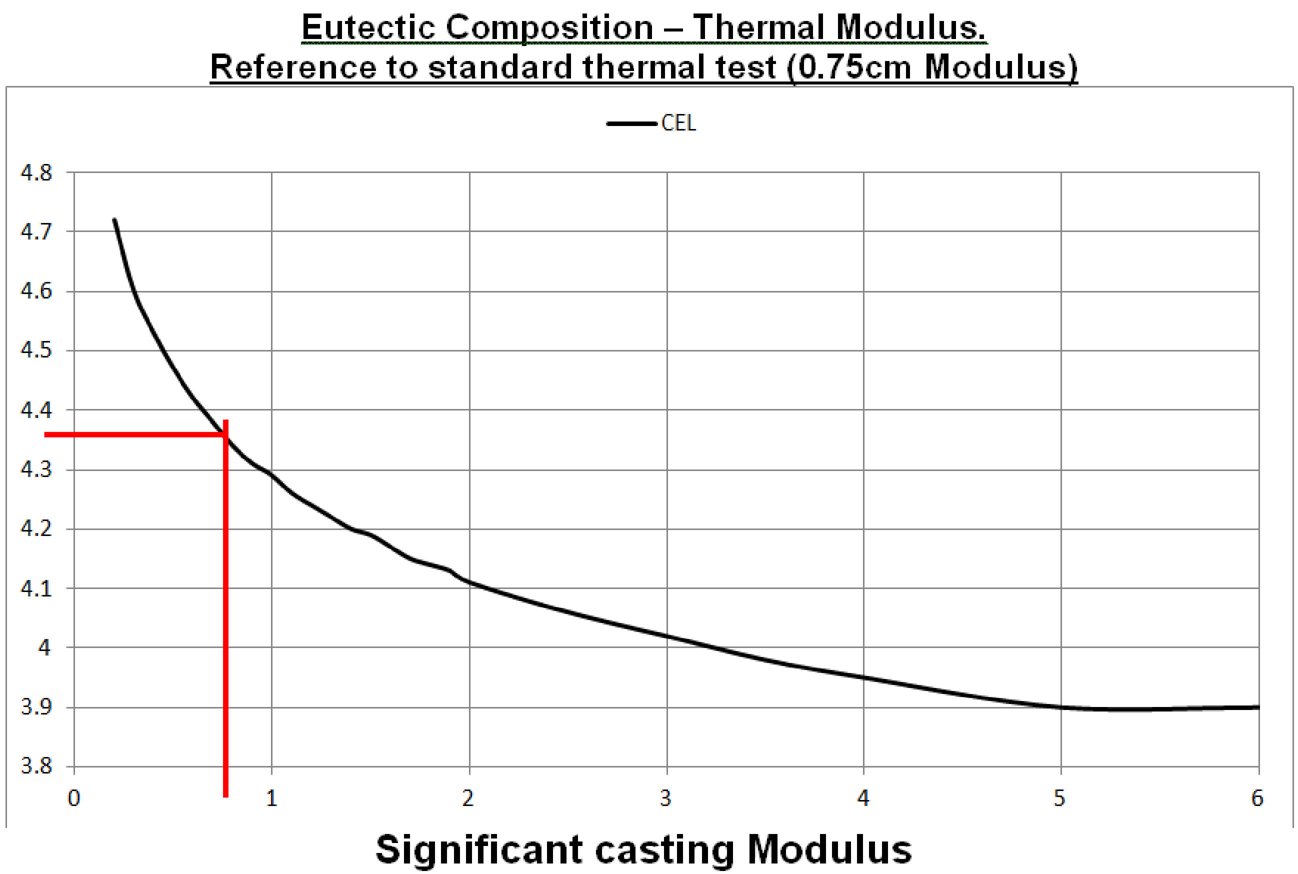
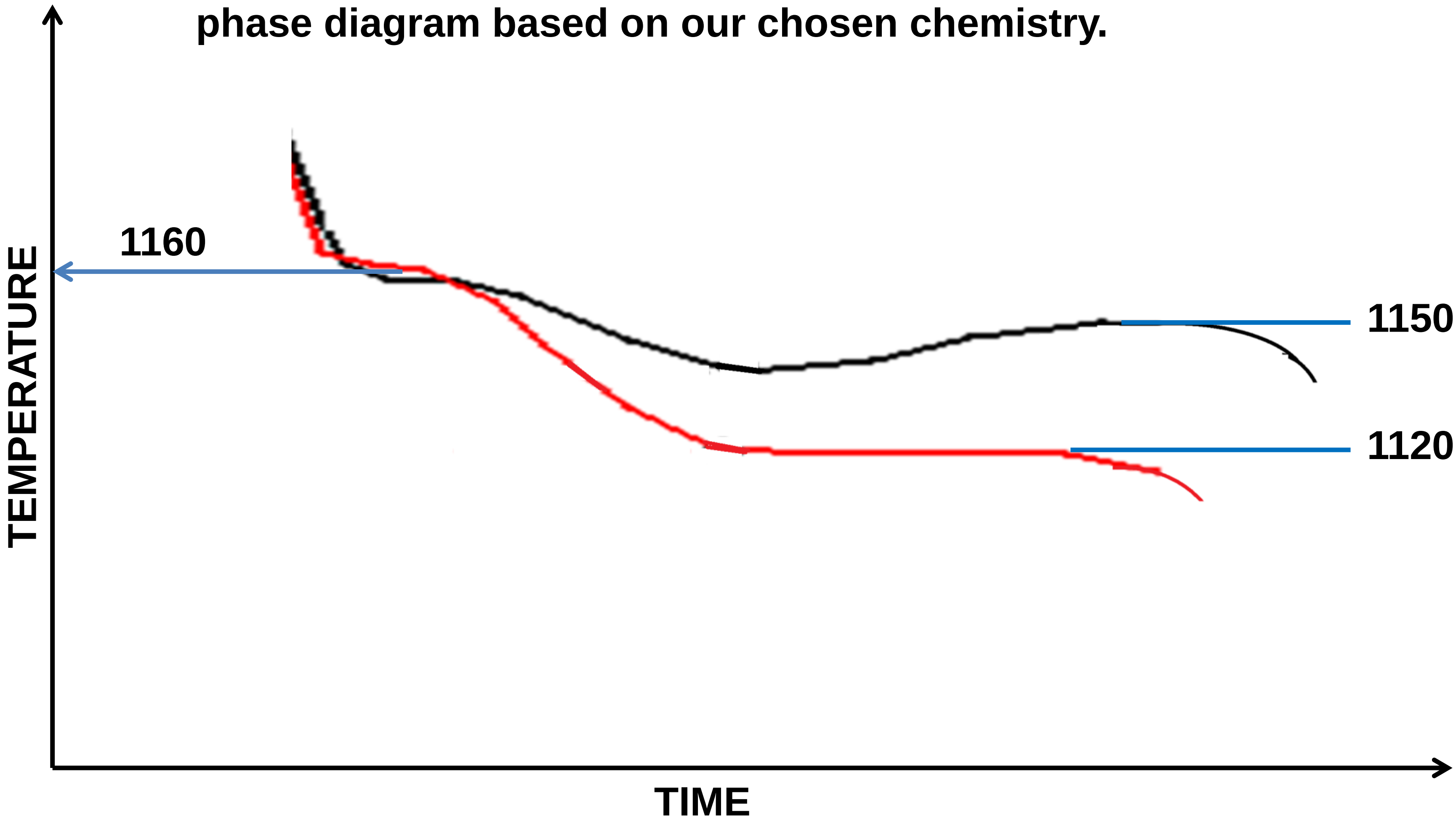


Choose a CEL, measured using a standard cup, to correspond to the significant casting modulus.
This will ensure eutectic composition within the casting.
In this example the final chemistry gives a Eutectic composition of 4.35

A Customised Phase Diagram

From 2 thermal curves we can construct a phase diagram based on our chosen chemistry.



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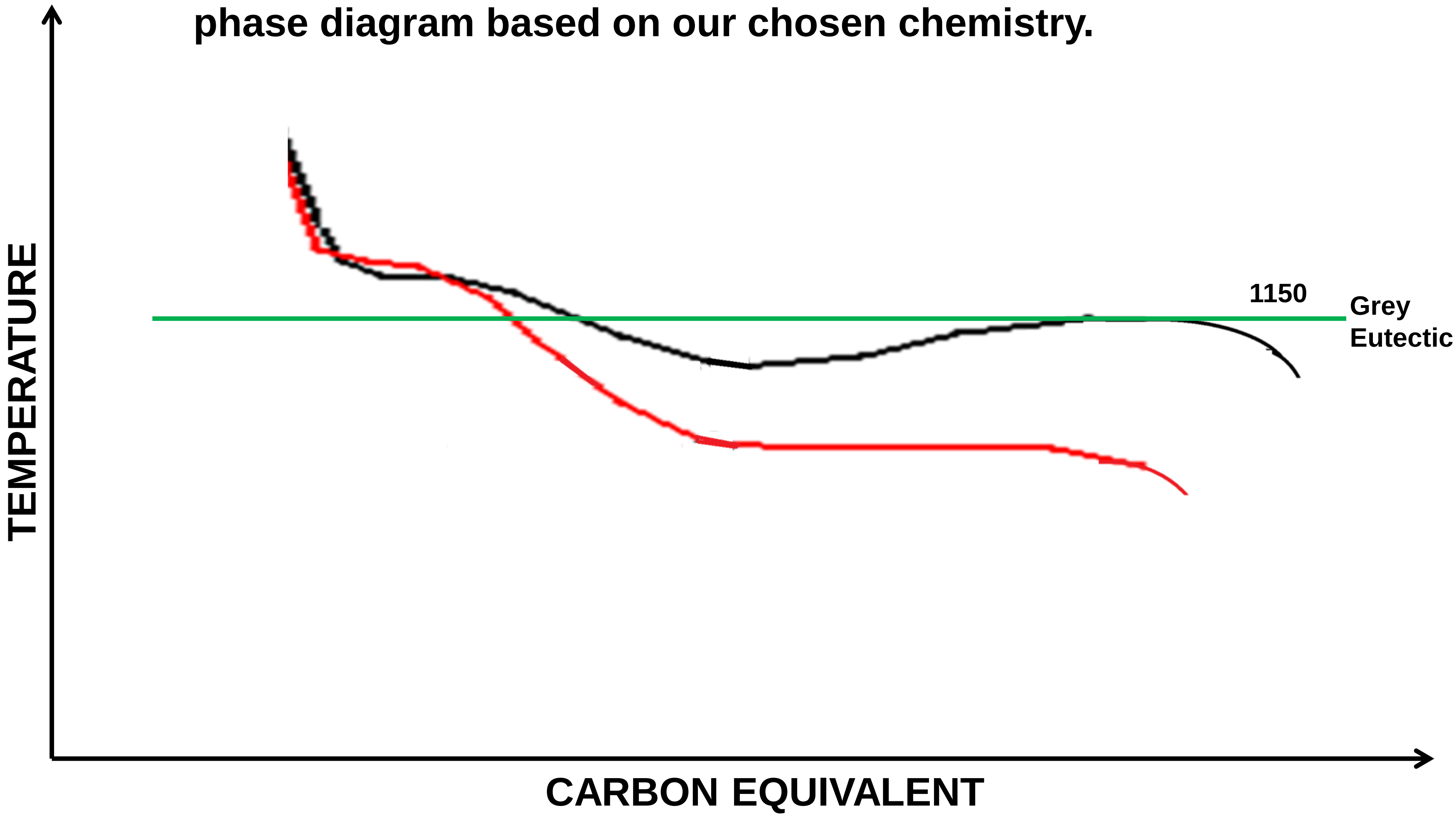

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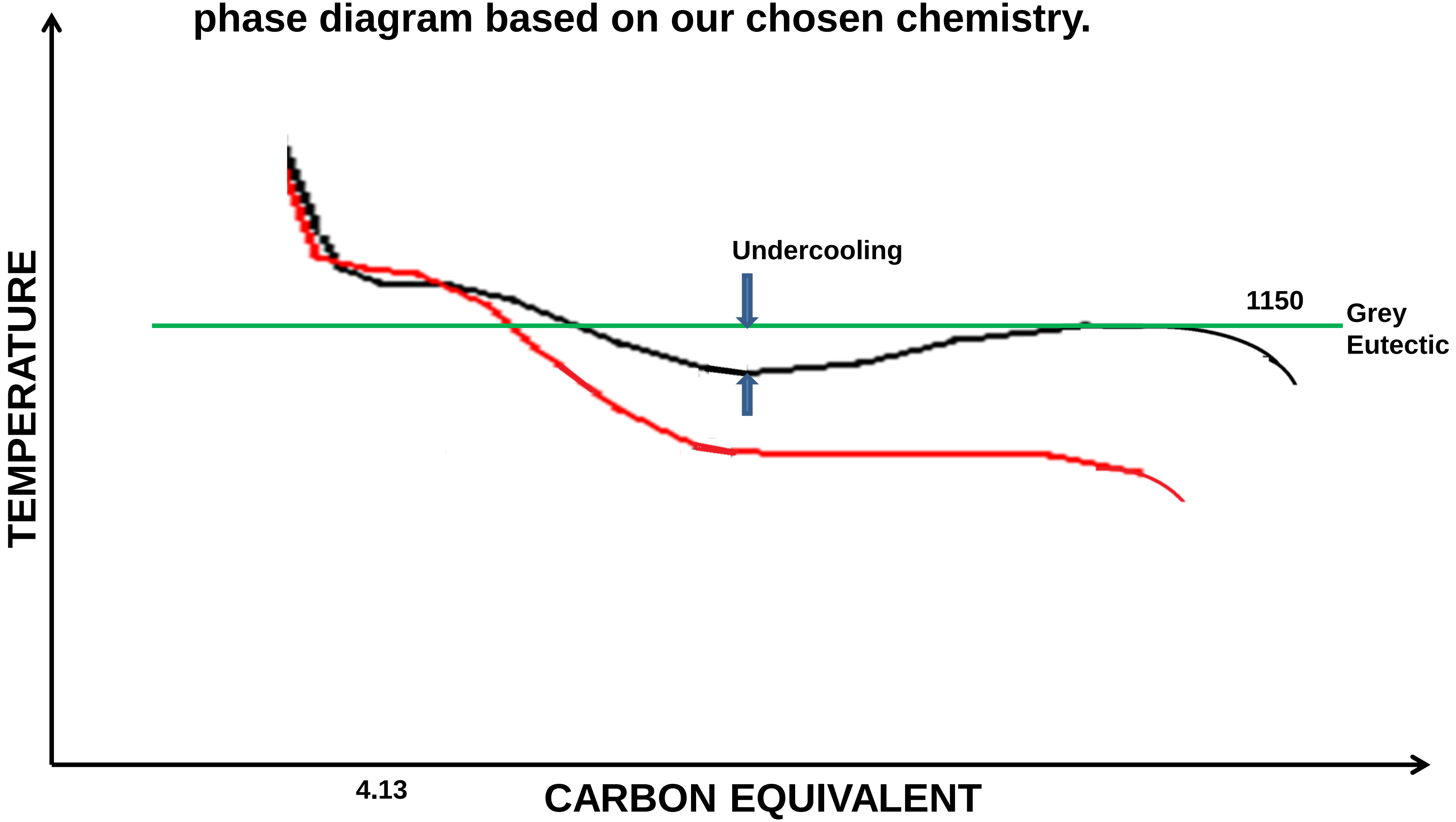

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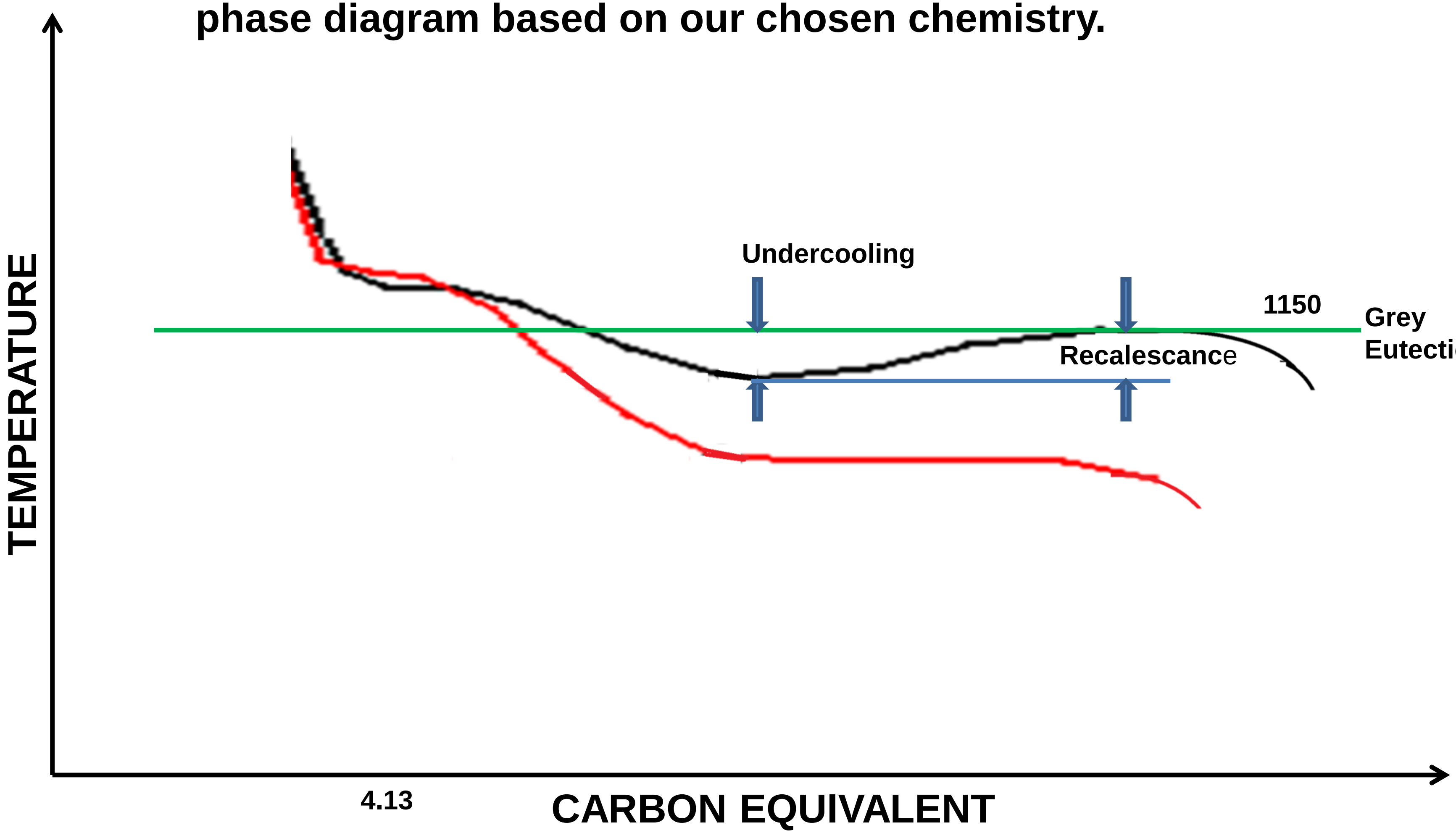

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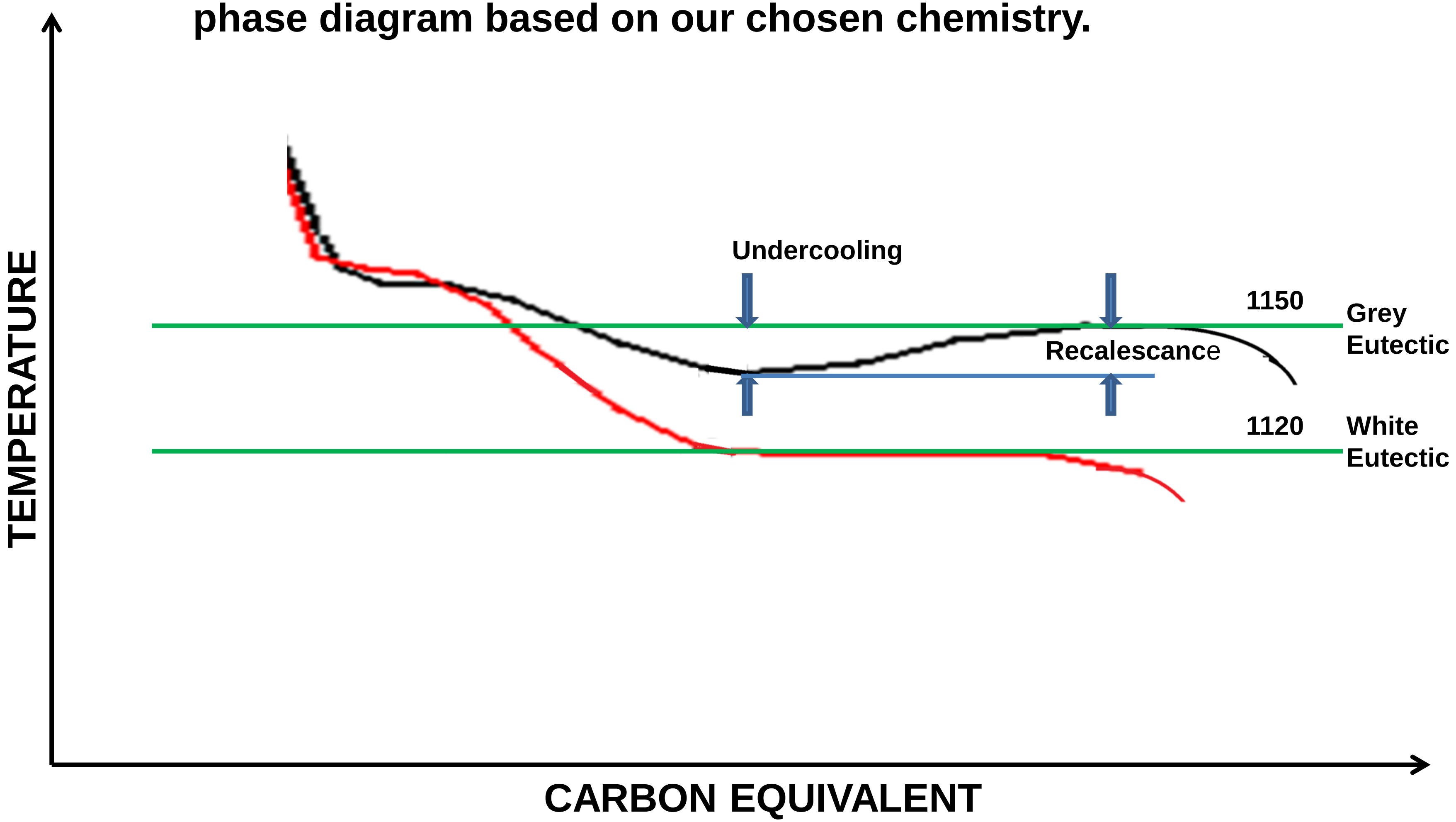

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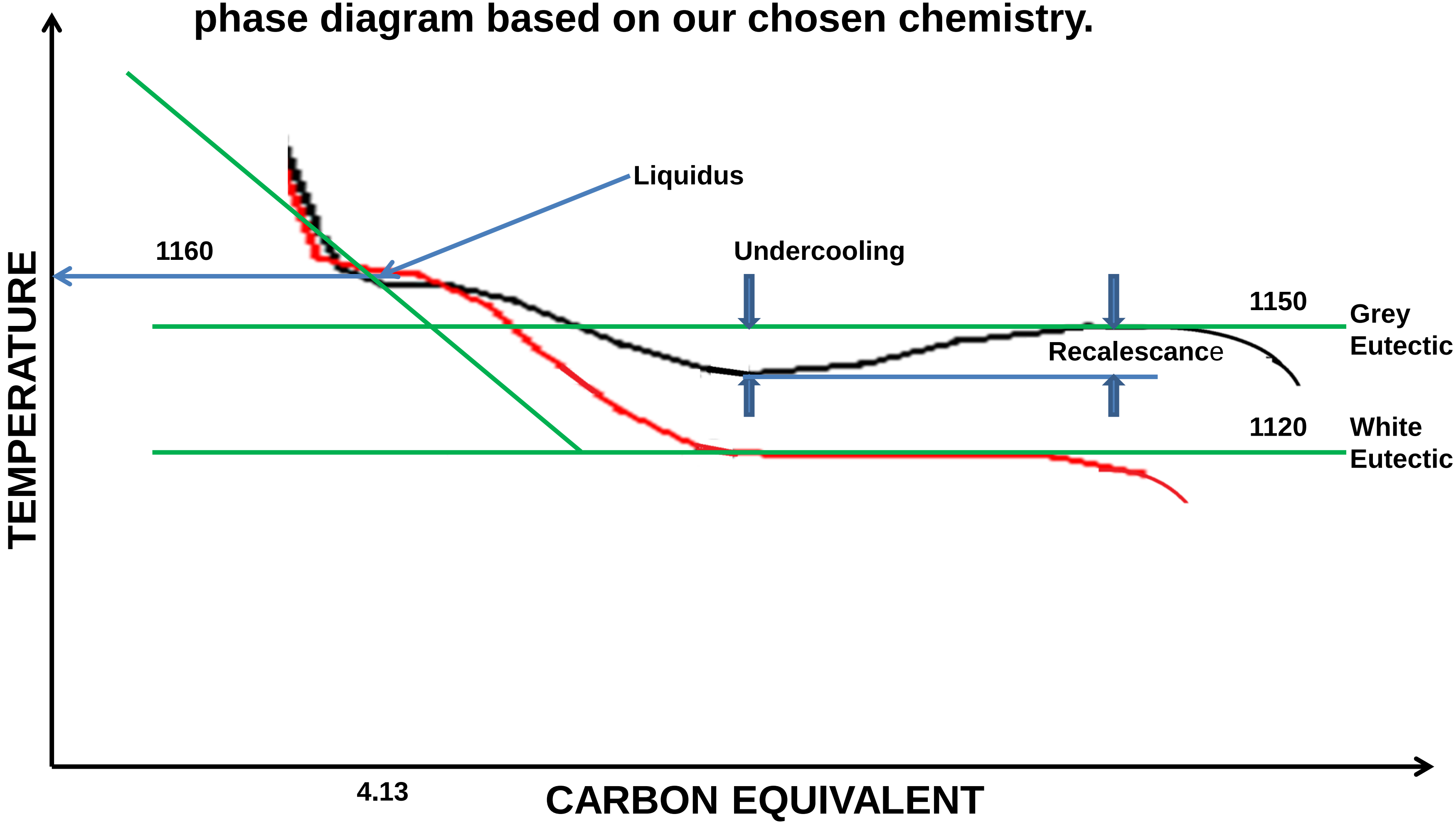

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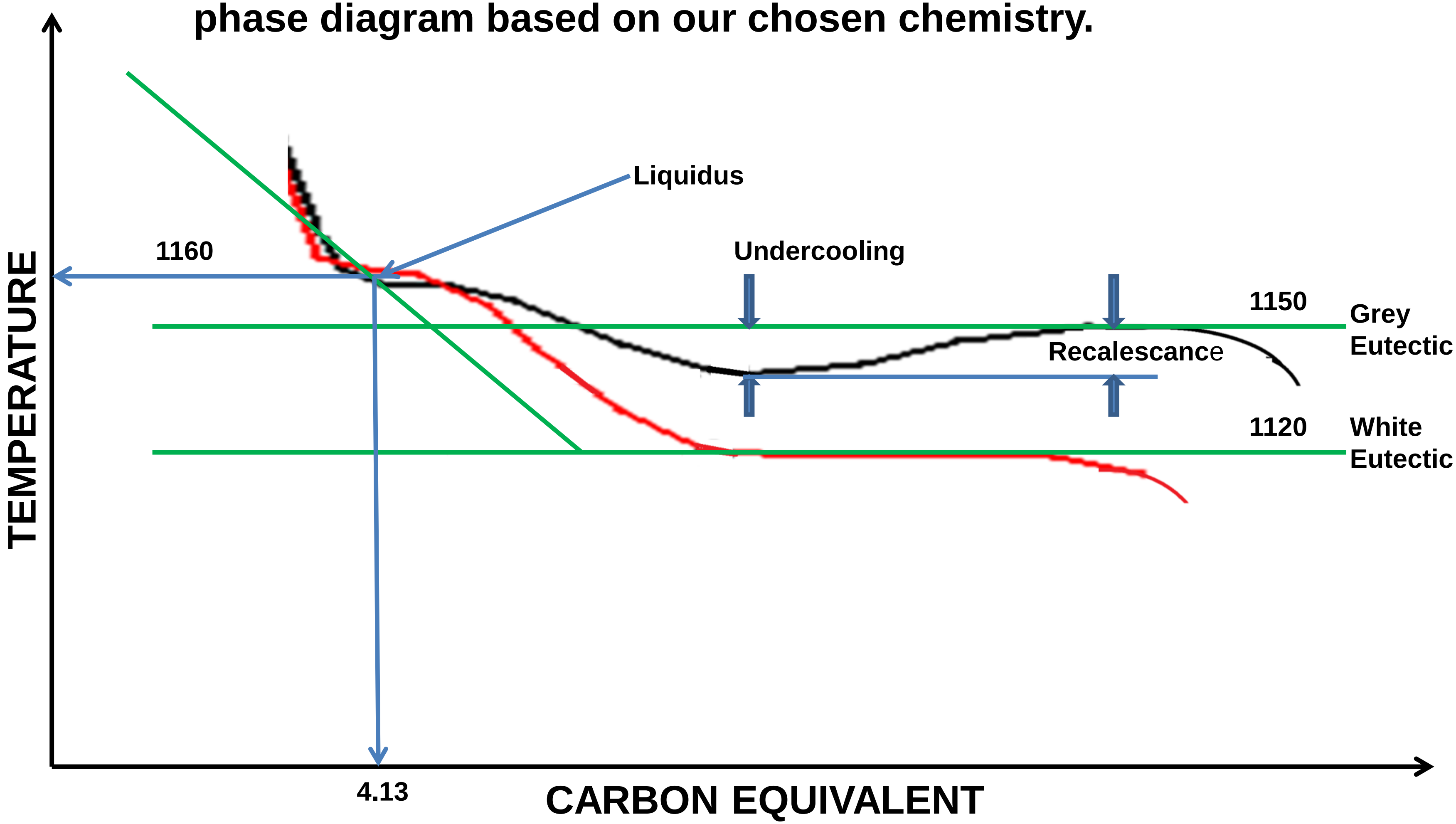

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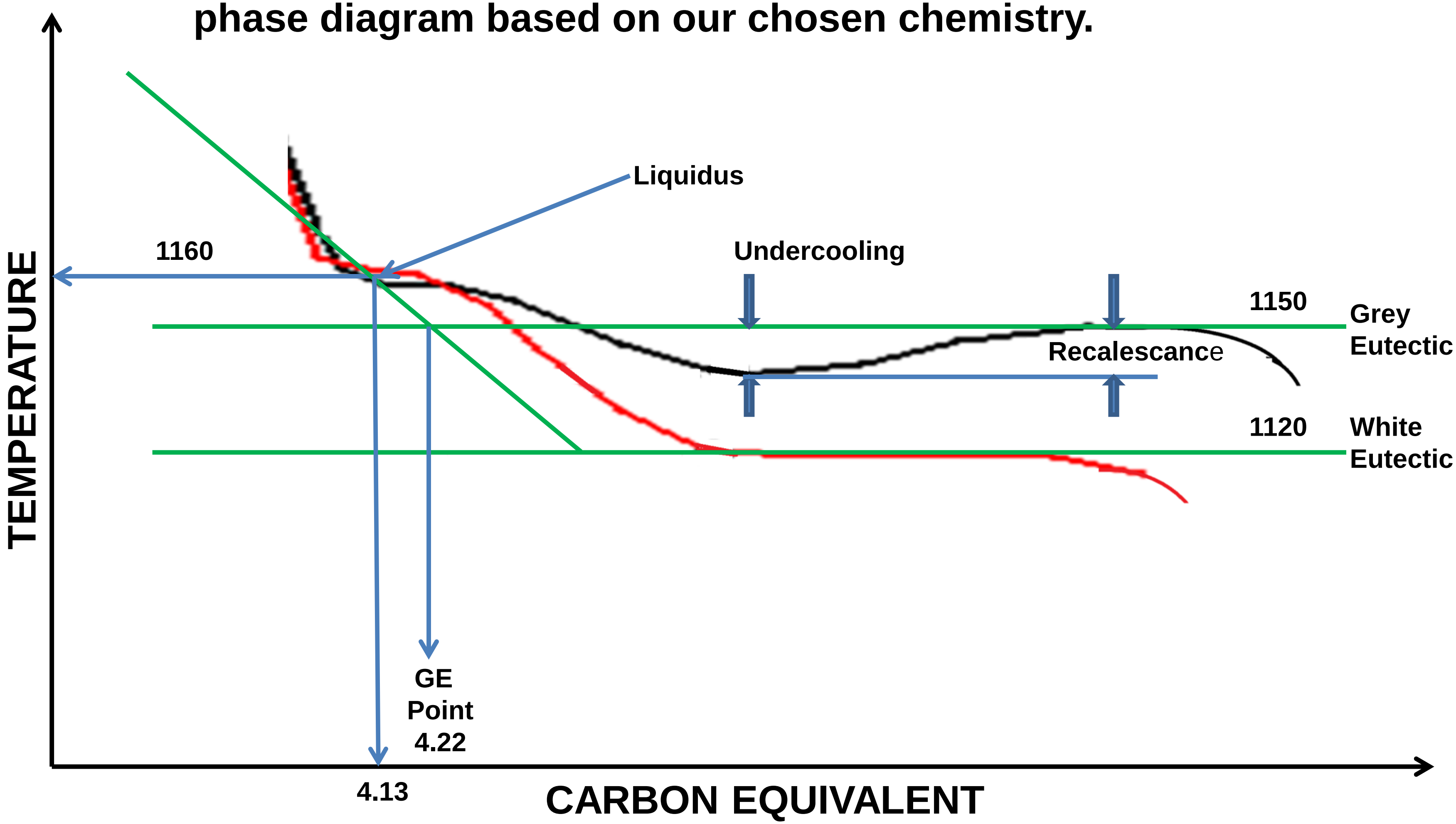

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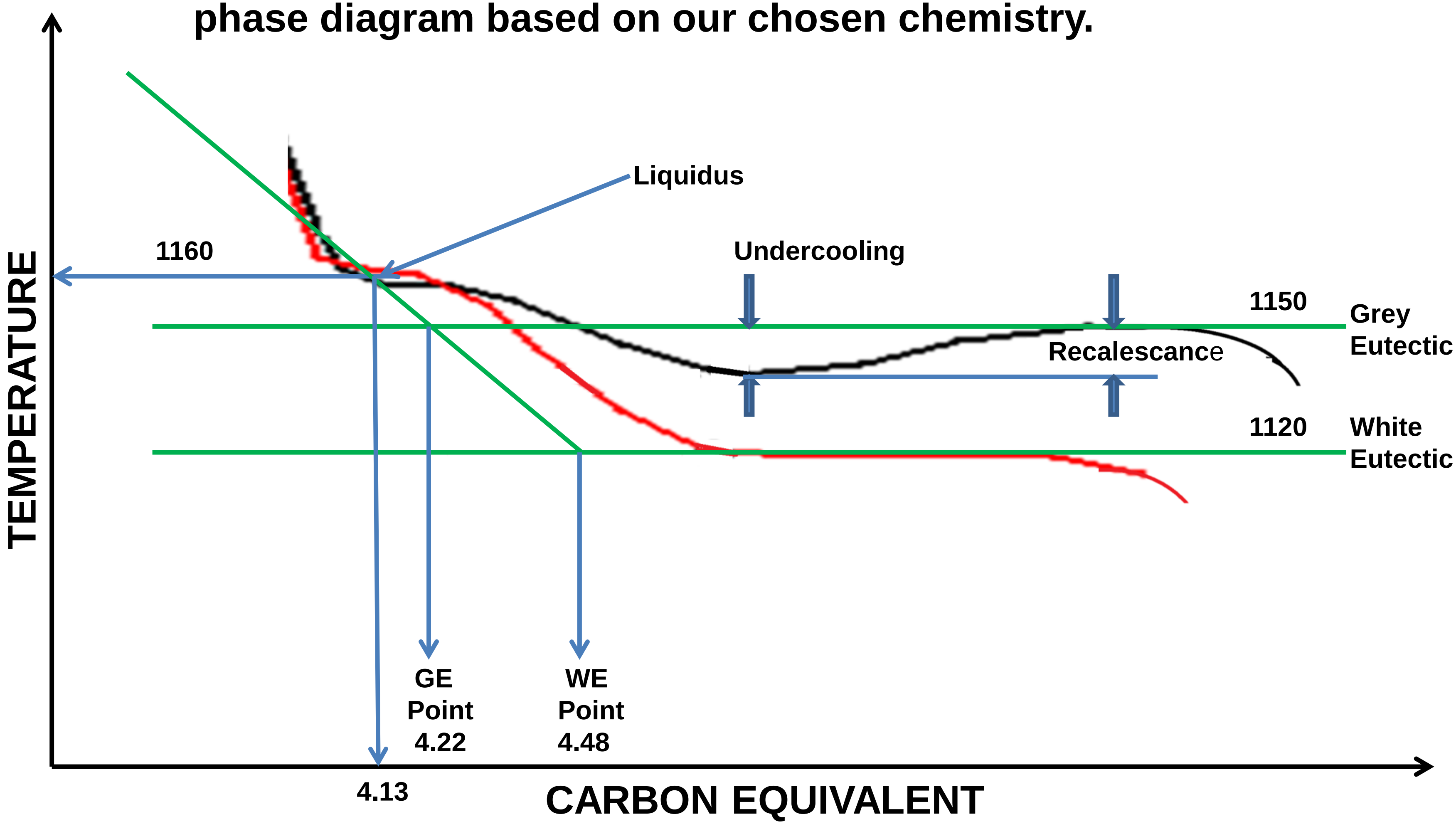

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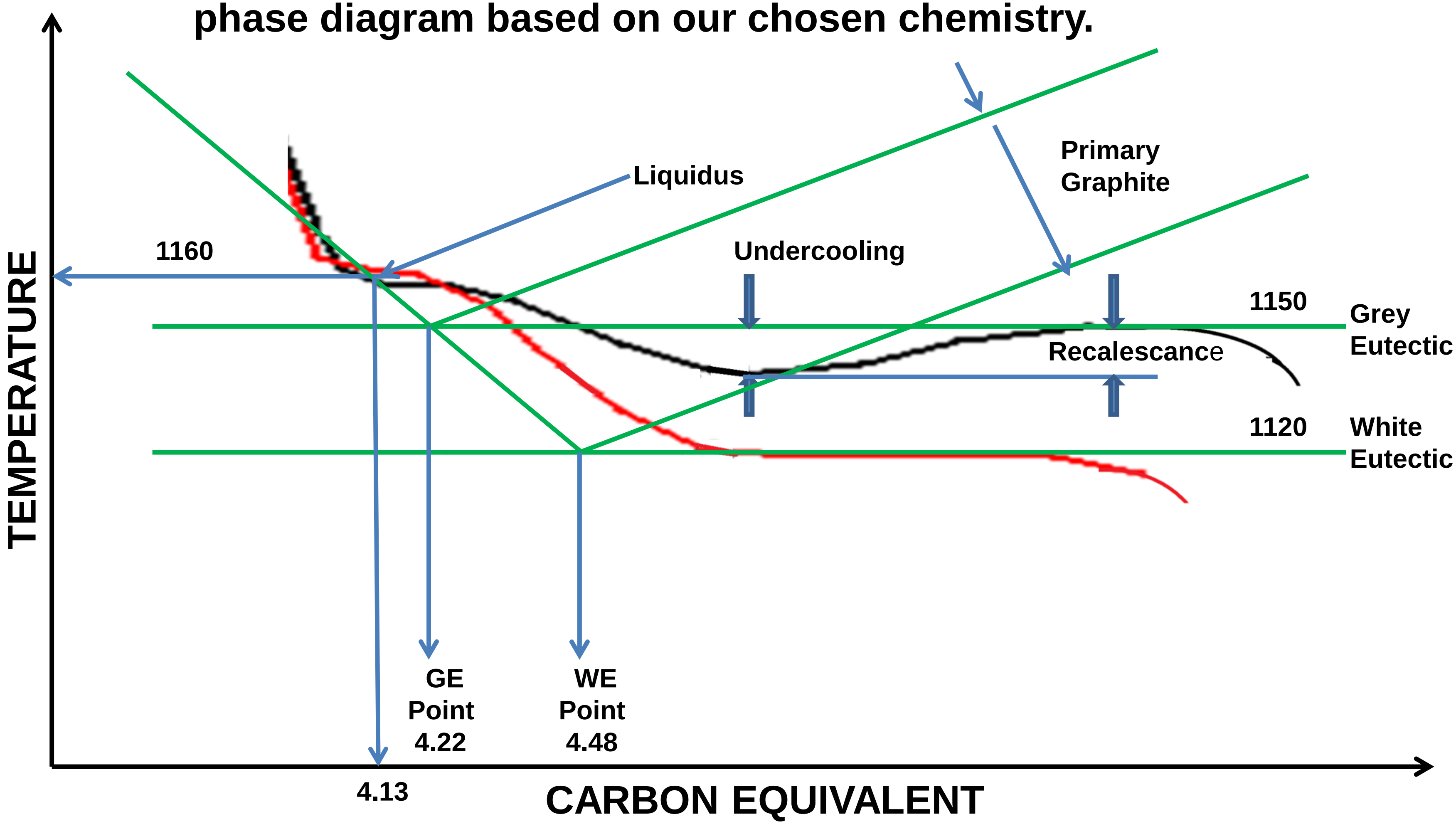

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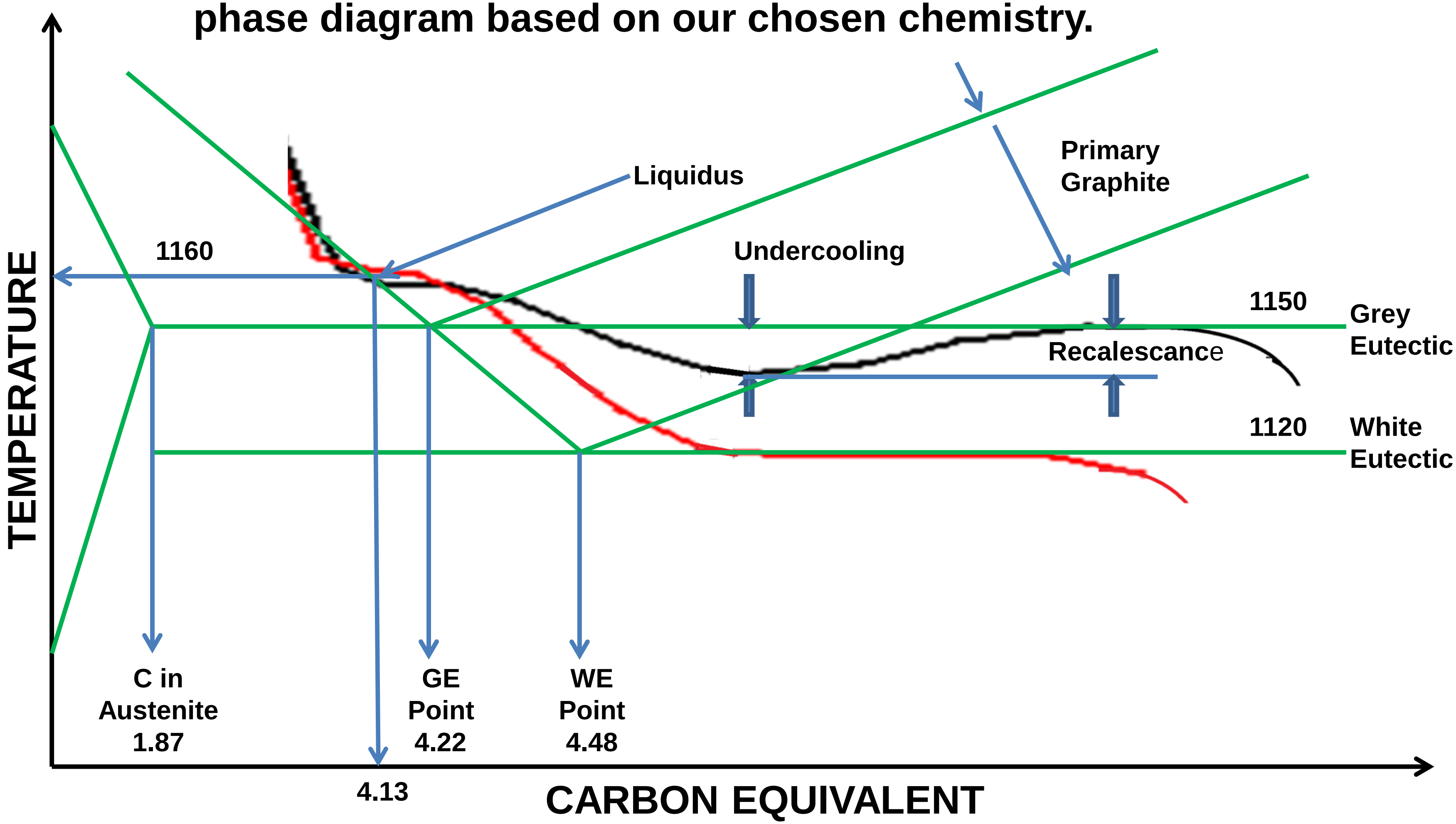

A Customised Phase Diagram

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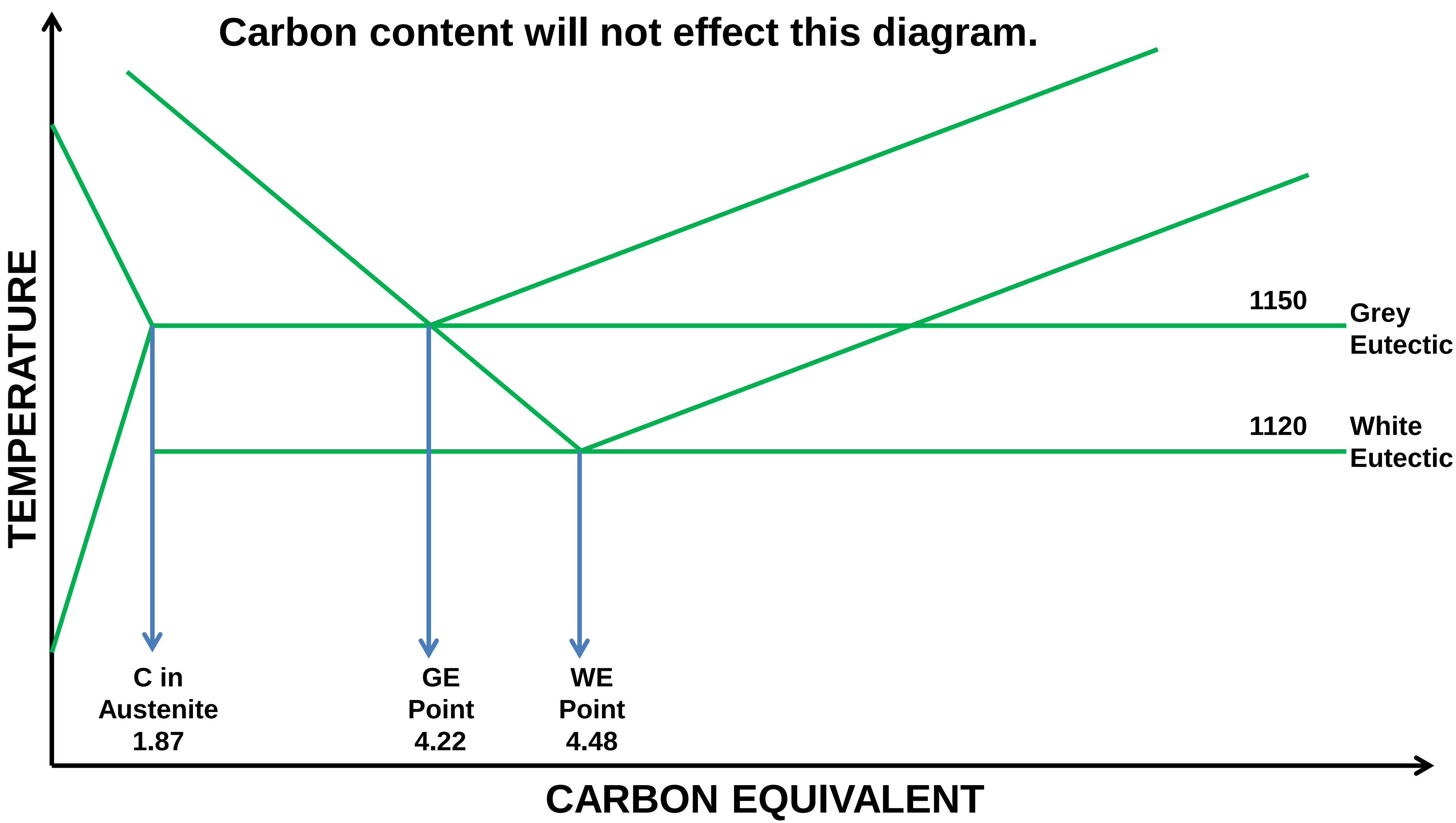

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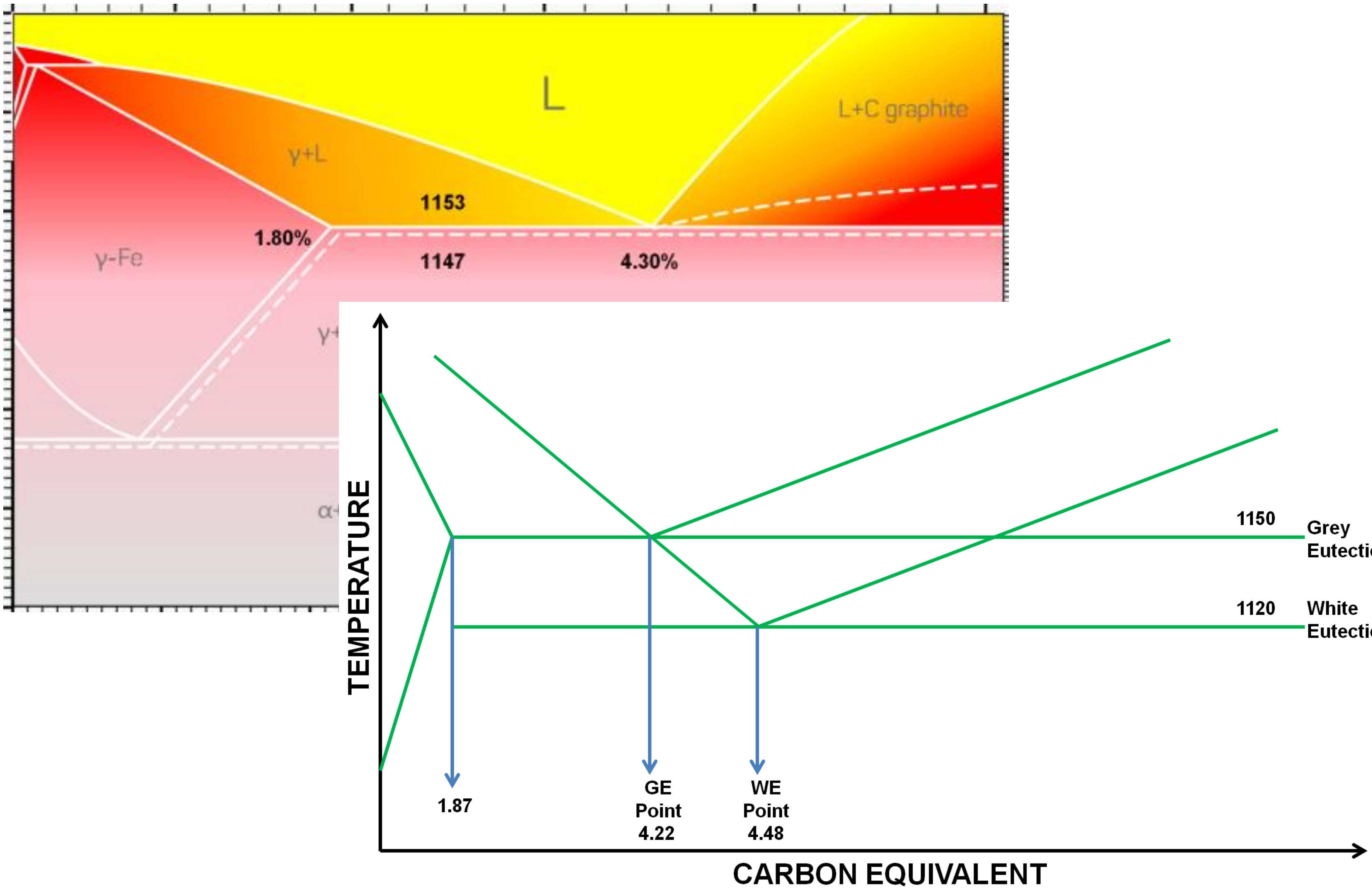


Copper Equivalent

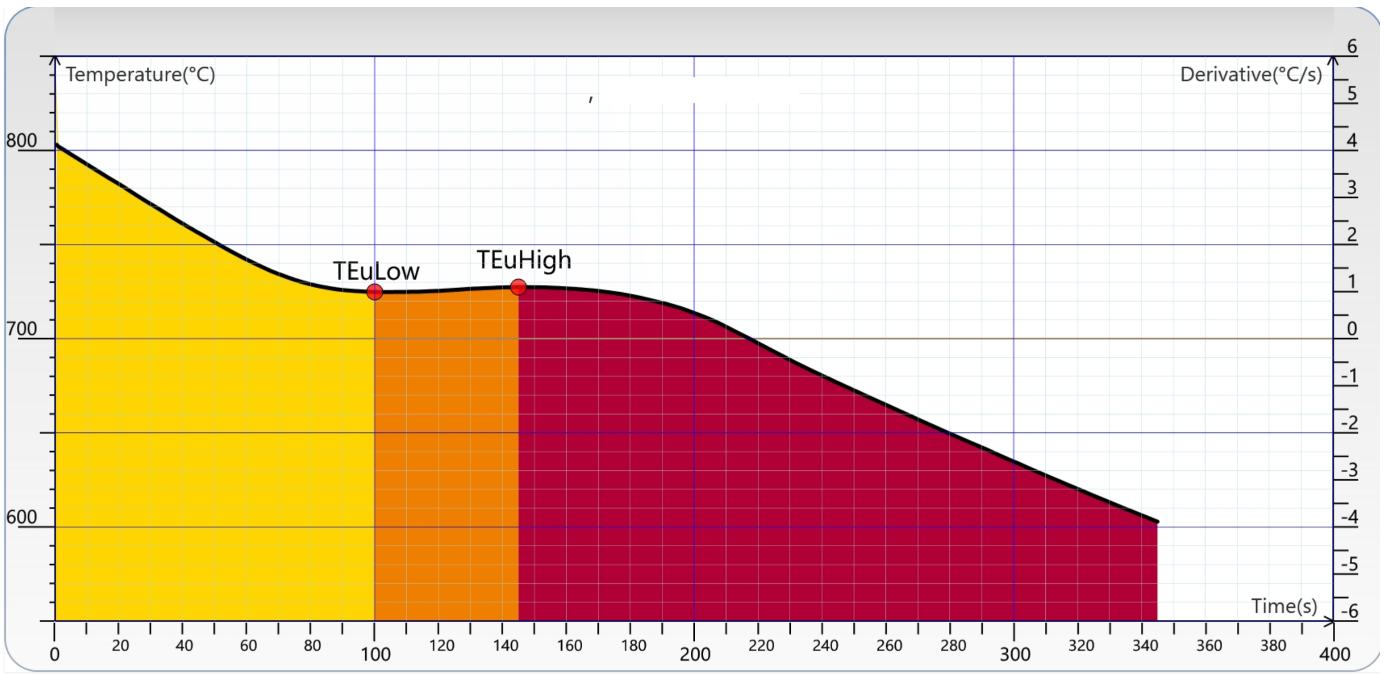
- Many elements influence Pearlite content to a greater or lesser degree compared to Copper.
- These elements can be given a **Cu Equivalent Value** based on their relative pearlitising strength compared to Cu.
- An overall Cu Equivalent Value can be established by adding all the individual contributions together.
- Controlling Cu Equivalent within tight limits will ensure consistent pearlite content and consequently consistent mechanical properties.
- Silicon has a negative Cu Equivalent, a Ferrite promoter, so increased levels of Silicon will require a higher Cu Equivalent Value to achieve a given Pearlite requirement.

Asmet Source of Strength	Effect of Elements															Asmet Source of Strength	
Element	C	Si	P	S	Mn	Sn	Cu	Ni	Cr	Mo	Co	Al	Ti	V	Sb	CEL	Cu Equiv
Input	2.700	2.600	0.014	0.007	0.500	0.030	0.600	0.020	0.040	0.005	0.000	0.000	0.020	0.020	0.000	**3.392**	**1.380**

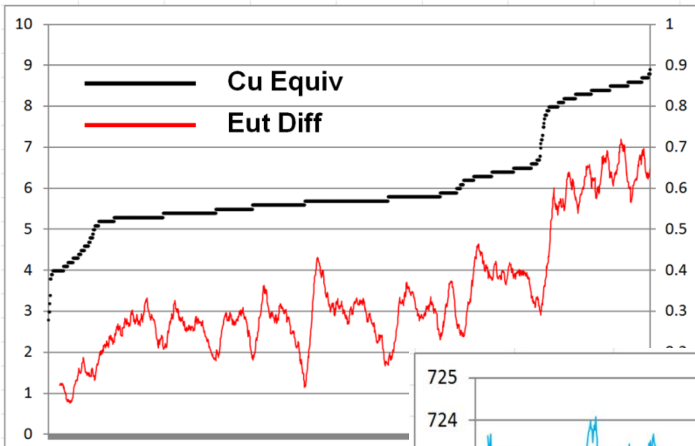
Copper Equivalent

- If the thermal sample is allowed to cool down to the Eutectoid reaction, the transformation temperatures and difference between upper and lower Eutectoid arrests can be measured.

- These values can be used to estimate Pearlite content and mechanical properties.

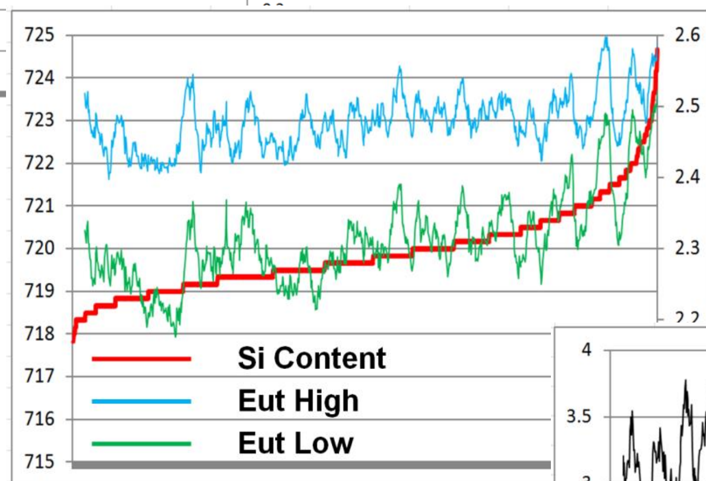


Copper Equivalent



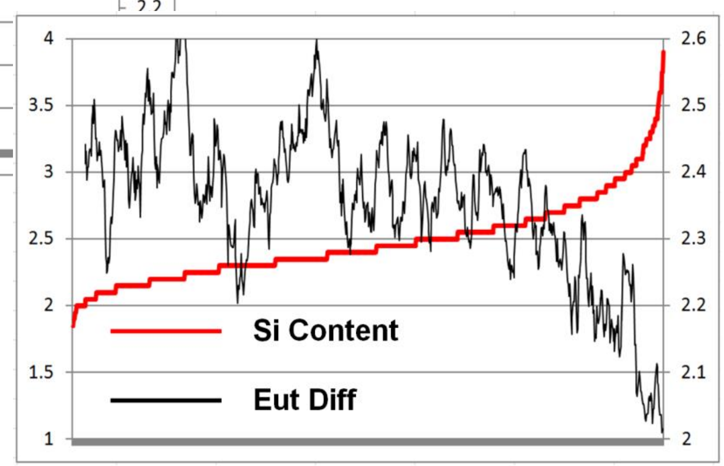
Cu Equivalent

Eutectoid Difference
High to Low



Silicon

Eutectoid Temps
High and Low



Silicon

Eutectoid Difference
High to Low

The Metallurgical Finger Print

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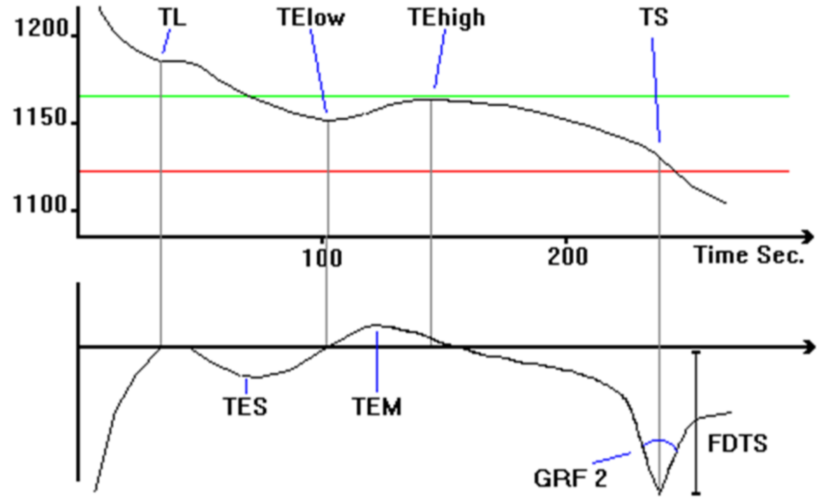
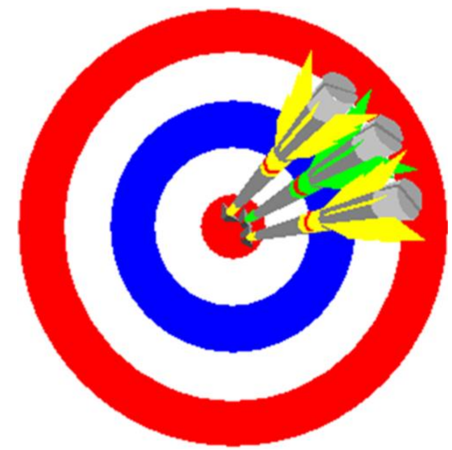
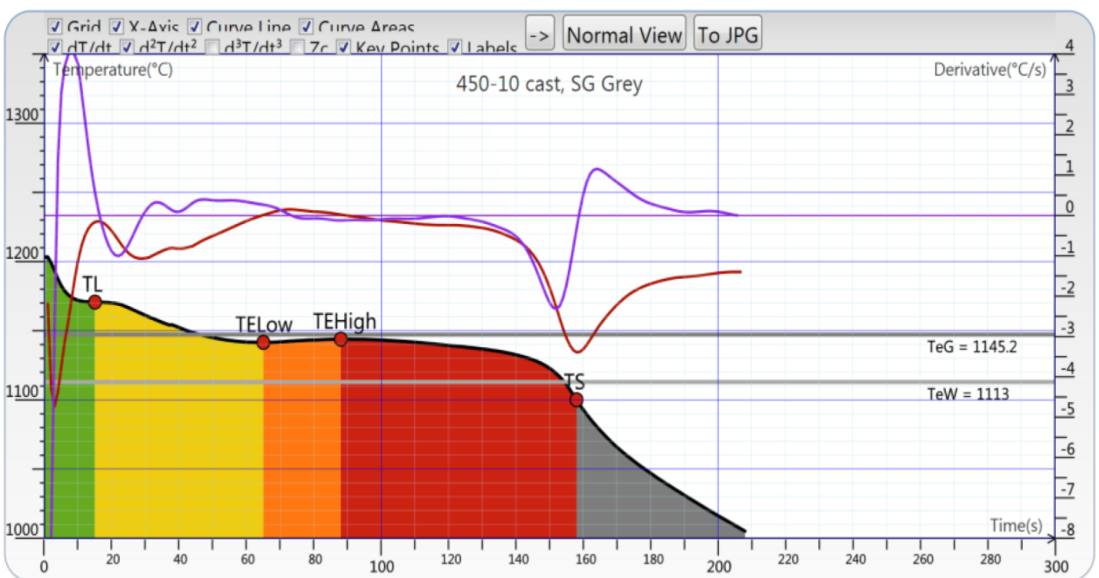






MQ = 92 OK

ACEL = 4.03

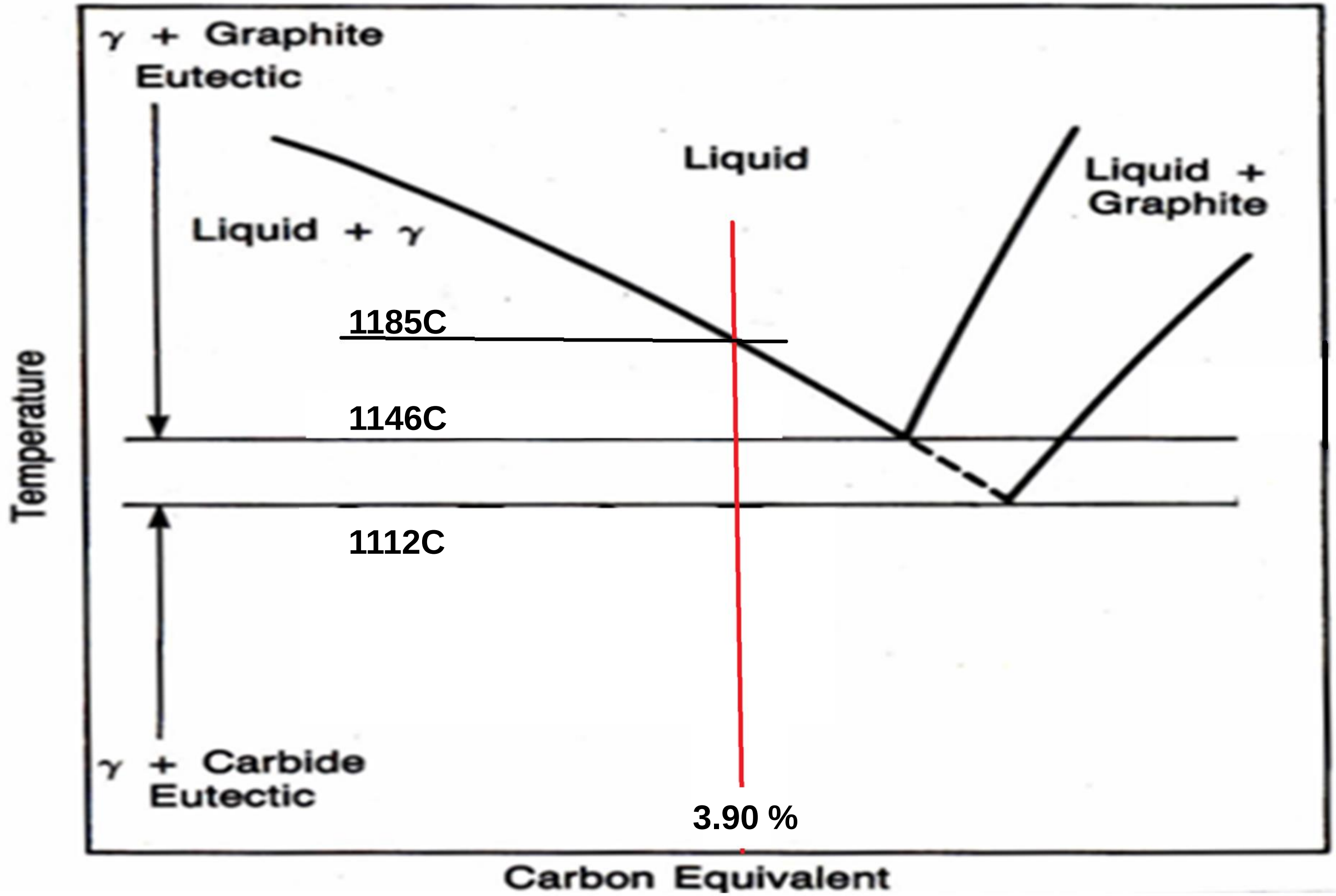
Indicator	Min	Current	Max	Fingerprint
TL	1165.0	1170.7	1172.6	
TES	1154.8	1163.3	1168.1	
dT/dt TES	-1.32	-1.06	-0.62	
S1	33.5	35.3	36.3	
TELow	1141.1	1141.6	1141.8	
R	1.9	2.3	2.6	
TEHigh	1143.0	1143.9	1144.4	
GRF1	68	81	88	
GRF2	28	38	56	
dT/dt TS	-3.84	-3.39	-2.58	
TS	1092.0	1100.1	1104.6	

Metallurgical Quality

”If it´s not measured it cannot be improved”

Example

Example



A grey iron chemistry with TL, GE, and WE established using ATAS. This foundry was having problems with variable casting hardness.

Example

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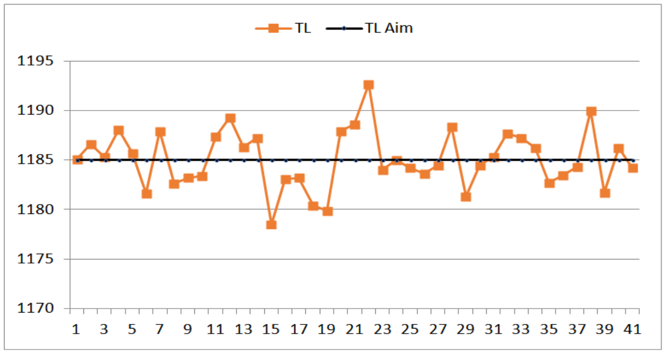
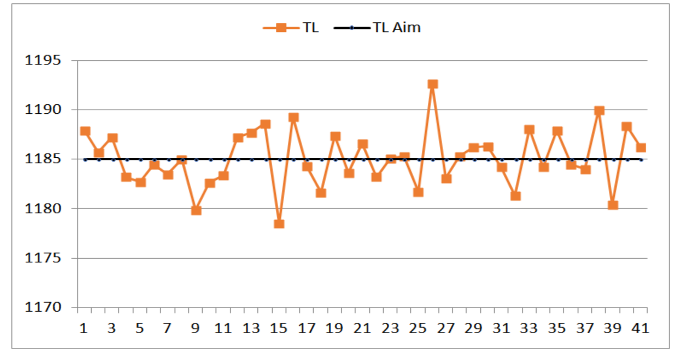
Data Sorted by Sample Order

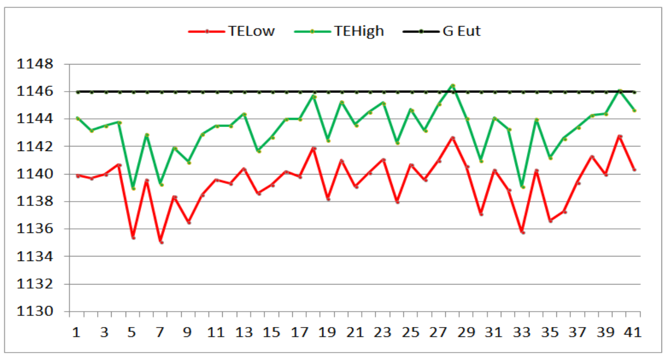
Data Sorted by TELow

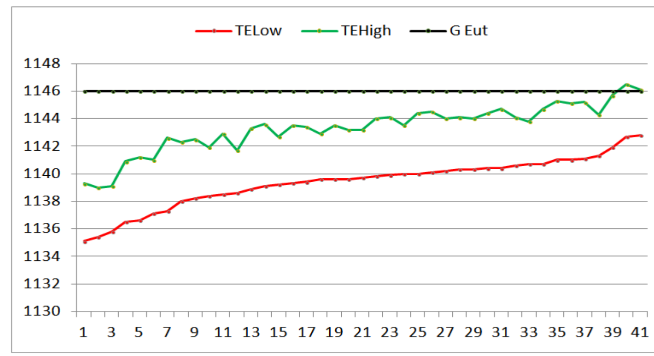
TL



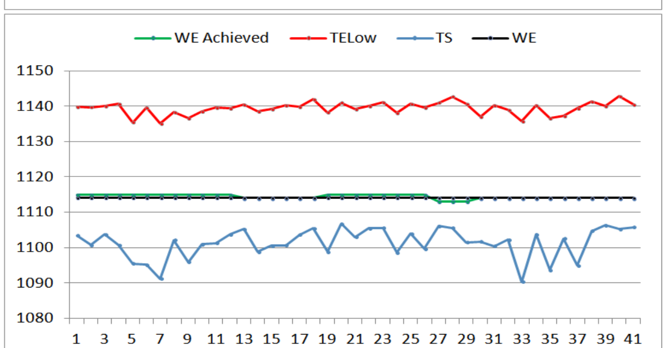


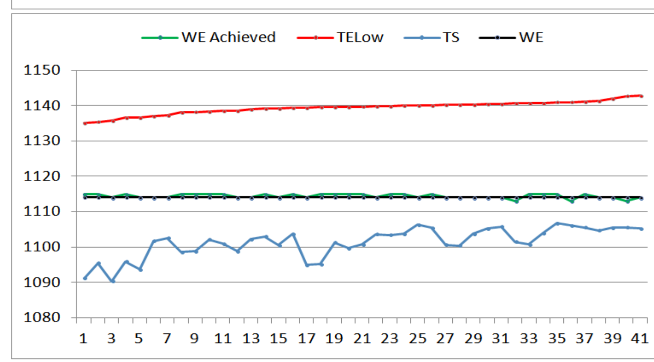
GE





WE

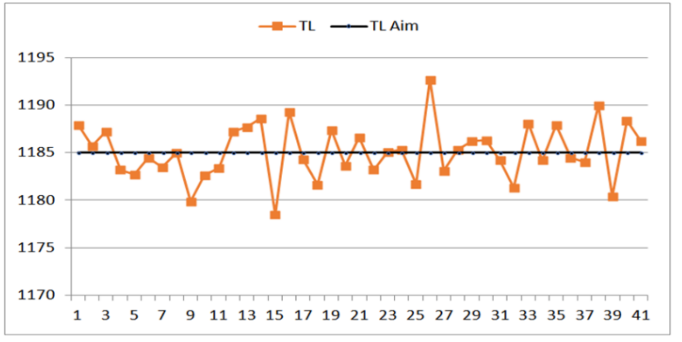




Example

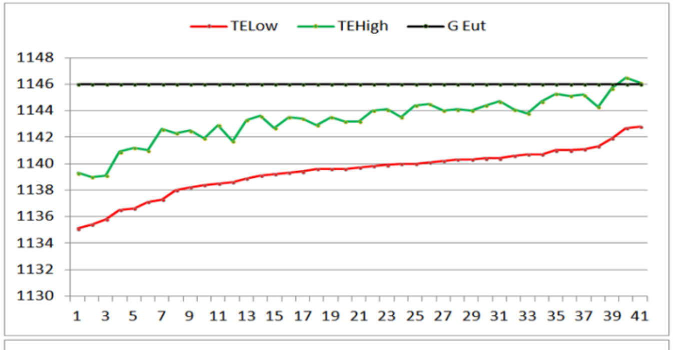
Data Sorted by TELow

TL



TL is generally well controlled to within +/- 5C (CEL Variation < +/- 0.05%)

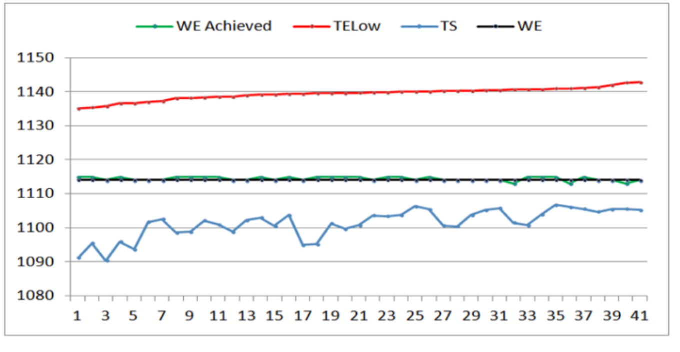
GE



TEHigh is not well controlled and is generally under inoculated.

When fully inoculated the castings are too soft

WE

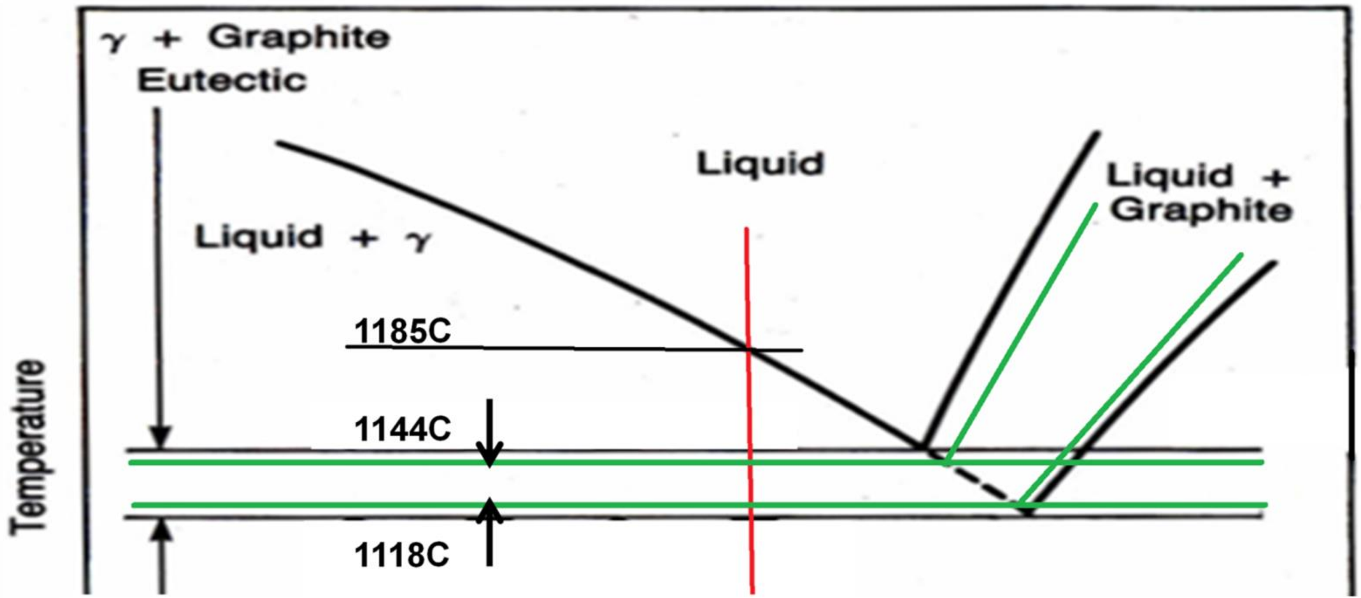


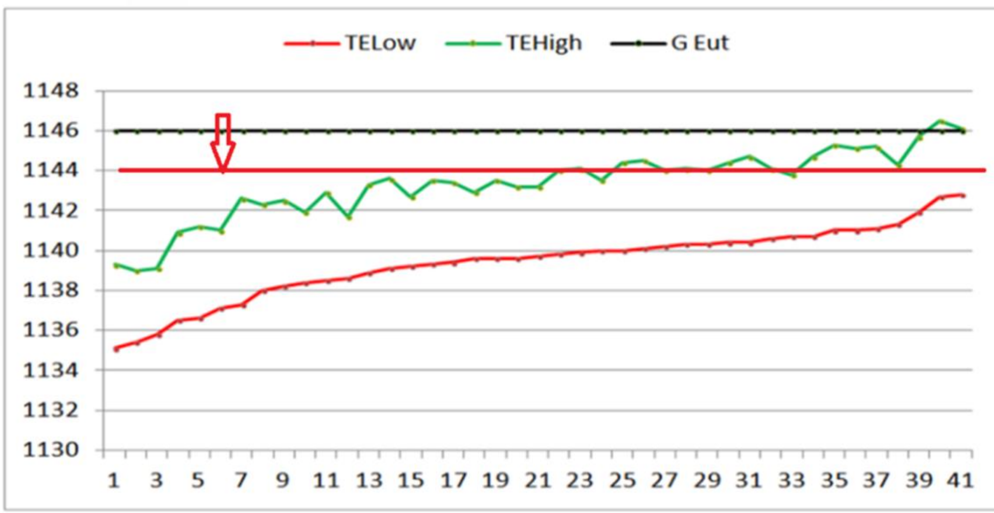
WE is well controlled to < +/- 2C

Too Hard

Too Soft

Example





Reduce the Grey Eutectic by 2C (by reducing Silicon)

Ensure the metal is fully inoculated, Grey Eutectic achieved.

Casting hardness will be as required and stable.

Process Recommendations

- **<u>Process Design</u>**
  Establish significant modulus (heavy section)
  Establish CEL (based on significant modulus)
  Establish Silicon content (chill free thin section)
  Establish Cu Equivalent (Pearlite content)
  Full chemistry established.

- **<u>Furnace Analysis (Tellurium Cups)</u>**
  Use Si Equivalent rather than true Si.
  Aim for low Si. Spectro measure and adjust alloying elements.
  Use Cu Equivalent rather than true Cu.
  Adjust Si to achieve WE temperture.
  0.1% Si decreases WE by 1.2C **or** 0.10% (75%) FeSi decreases WE by 1C
  Aim to keep WE to within +/- 2C
  Trim C to achieve CEL within +/- 0.05%

- **<u>Ladle Analysis</u>**
  Measure and establish TL, GE and WE.
  Control undercooling, R, (1-3C) , and ensure GE is reached with inoculation procedure.
  Use S-Te Cups to measure WE with nodular production.

Conclusions

- The chosen chemistry defines:-

The Liquidus Temperature (TL)	(Carbon Equivalent - CEL)
The Grey Eutectic (GE)	(TEHigh if fully inoculated)
The White Eutectic (WE)	(Silicon Equivalent)
The Pearlite Content	(Cu Equivalent)

- The Liquidus temperature is mainly influenced by the carbon, silicon and phosphorus content (CEL)
- GE and WE are influenced by melt chemistry, **not** Carbon content.
- TL and WE can be measured using Te cups (S-Te cups for treated Nodular Iron).
- GE must be measured using a fully inoculated sample, poured into a plain cup (Grey Sample).
  Fully inoculated, TEHigh = GE
- The Grey Eutectic Temperature is used to define the eutectic point, eutectic chemistry and influences the amount of primary austenite precipitated.
- Undercooling should be controlled to within 3C.
- If TEHigh meets GE, graphite precipitation has been maximised.
- If TEHigh does not reach GE, graphite precipitation has not been maximised and inoculant addition needs to be increased.
- For a given chemistry the aim should be to achieve the reference temperatures (TL,GE, WE) within limits and **<u>with minimal undercooling.</u>**

- **Process Control using ATAS <u>will</u> help you to achieve these targets.**

Thank you for listening